STRANGERS IN A STRANGE LAND: INDUSTRY AND ACADEMIC RESEARCHERS

by

BETH-ANNE SCHUELKE LEECH

(Under the direction of Barry Bozeman)

Abstract

Technology transfer between the public sector and industry is often viewed as the key to the development and use of new knowledge. The U.S. federal government has pushed for increased use of government funded inventions and discoveries, from both government and university labs. However, professional conventions and organizational cultures can make it difficult for industry and academic researchers to work together effectively. This dissertation examines the role that institutions and academic disciplines have on the behavior and values of academic researchers.

The dissertation is comprised of three essays, each one exploring a different aspect of the relationship between academic researchers and technology transfer activities.

The first essay explores the differences between research scientists and engineers to see whether disciplinary conventions create a higher or lower propensity to be involved with industry. The results of the essay show that there are strong disciplinary differences between scientists and engineers. Engineers are more likely to spend time working with industry, to act as a resource for industry, to actively collaborate with industry, and to believe that funding decisions should consider the overall benefit to society that the research provides.

The second essay looks at the influence of three types of departmental research resources – human, financial, and physical – on individual researchers. The results show that different resources have different influences on industrial involvement activities. Human resources have a consistently positive influence on industry involvement; financial resources have a mixed influence, while physical resources have a consistently negative effect.

The final essay examines the influence of research colleagues within University Research Centers (URCs). Specifically, it examines whether researchers are more likely to be affiliated with URCs dominated by their own discipline. It also investigates whether working in a university research center dominated by engineers leads to different collaborative behavior for research scientists. The results show that the majority of researchers do not cross disciplinary boundaries to work in URCs. In addition, scientists that work in engineering-dominated URCs exhibit different industrial involvement behavior than researchers affiliated with non-engineering dominated URCs.

INDEX WORDS: University-Industry Collaboration; Technology Transfer; Research Collaboration; Academic Researchers; Research Resources; Scientists and Engineers; Science and Engineering

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Dedication

Dedicated to my dear father, Robert Otto Schuelke –

a real gentleman, kind, intelligent, wise, sweet, curious, understanding.

Though he did not live to see the completion of this particular adventure,

he is always with me in Spirit and Love.

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Chapter 1: Academic Researchers and Industry

Introduction

In recent years, there has been widespread interest in understanding the knowledge creation and dissemination processes that occur in a country's innovation system. To understand these processes, it is necessary to understand the institutions in which they occur and the actions and values of the individuals within them. From a broad perspective, a nation's innovation system is comprised of a complex array of organizations - small businesses, large industrial organizations, universities, start-up companies, research centers, joint-ventures, think-tanks, government laboratories, financial institutions, private investors, and venture capitalists (Crow and Bozeman, 1998). These institutions interact and collaborate for the purpose of generating, disseminating and utilizing knowledge and technology (OECD, 1996). The goal of these activities is to promote economic activity and prosperity through the transformation of scientific knowledge into commercial products.

This innovation system has undergone profound changes in the last thirty years, which has given rise to new institutions and new activities. With the adoption of Vannevar Bush's proposal for post-World War II R&D funding in *Science, the Endless Frontier* (Bush, 1945), research universities became central to innovation in the United

States. Private firms focused on applied research, while universities focused on building foundational, curiosity-driven knowledge. Government laboratories covered a range of activities, consistently focused on strategic or classified research projects. The vast majority of the funding for public research was through the government.

Declining national competitiveness in 1970s and 1980s in the global manufacturing sector pushed policy makers to look for ways to assist industry. Numerous initiatives were launched to try to link universities and industrial innovation and to encourage collaboration between the sectors (Mowery, Nelson, Sampat, and Ziedonis, 1999; Mowery and Sampat, 2001). Legislation[1] was enacted to permit contractors of federally funded research to patent and license inventions in the hopes that they would be in a better position for exploiting scientific discoveries. Government and universities labs alike were viewed by policy makers as "treasure chests" – repositories – of technology and knowledge that had directly applicability to private industry (Ham and Mowery, 1998). At the same time, the public at large began to question the public expenditures and sought accountability and minimization of public spending (Schein, 1996a). Public research labs have faced additional pressures from public officials who sought to reduce public expenditures by reducing funding. With an ability to patent and license their intellectual property, university administrators began to look to the work done in their labs as holding potential for substantial revenues – a treasure chest of another sort.

The rise of commercialization in public labs corresponded to a decrease in corporate research. For much of the twentieth century, US firms kept strategic R&D in

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[1] For example, the Bayh-Dole Patent and Trademark Amendments Act of 1980 and Federal Tech Transfer Act of 1986

house (Mowery, 1983). Faced with declining competitiveness, rising costs, and resource shortages, private sector organizations in the 1970s and 1980s began to look to improve efficiencies and operations.

Rising costs of production, increased pace of technology development and diffusion, and intensified globalization of markets have changed the nature of competition for most businesses (Porter, 1986; Bettis and Hitt, 1995; Johnson, 2006). It is difficult for most organizations to operate in complete isolation. Even small businesses are affected by the costs of manufacturing overseas. Businesses have tried to reduce their R&D expenditures; many firms have stopped collaborating in in-house basic research aimed at creating knowledge that directly fed into their commercial entities (Crow and Bozeman, 1998; Johnson, 2006). At the same time, the pace of business and of knowledge creation made it essential for firms to acquire new knowledge, technologies, and processes to incorporate into their operations and products. While businesses have been divesting themselves of unnecessary internal expenditures and outsourcing everything from production to accounting to reduce costs, they have also been looking for ways to integrate external sources of knowledge and technology (Cockburn, 2005) because there is an increasing need to be innovative (Johnson, 2006) and the complexity of knowledge needed for the design, development, and manufacturing of products makes it impossible to have it in-house (Brusoni, Prencipe, and Pavitt, 2001).

Coupled together, these factors led to an increase in the pressures for both private firms and public research organizations to work together. University-Industry collaborations have become crucial to successful global competition and new product development for many firms. Mansfield (1998) calculated that 10% of all new products and processes introduced in the drug and medical products, information processing, chemical, electrical, instruments, metals, and machinery industries could not have been developed without academic research. University-Industry collaborations have brought biotechnology, lasers, recombinant DNA, liquid crystals, synthetic polymers, and a large array of computer technologies to the marketplace (Rosenbloom and Spencer, 1996; Owen-Smith and Powell, 2003). Innovation, technology transfer, and university-industry collaborations have become almost synonymous with global competitiveness and economic development.

Collaboration

Scientific research and development has become a major national policy focus (NRC, 1999). Science and technology are viewed as essential to creating sustained economic growth and improving the living standards of U.S. citizens (NRC, 1999). Science has been tied to economic development and global competitiveness (NRC, 1999; Augustine, 2005). Universities have become a major focal point, since a substantial amount of publicly-funded research and development is performed in universities. In a survey conducted of manufacturing firms, Cohen, Florida, and Walsh found that two-thirds of the firms believed that academic research was at least “moderately important” to their own internal R&D efforts (Cohen, Florida, and Walsh, 1996). In addition, university research has proven essential for product development in some industries, such as the pharmaceuticals and biotechnology industries (Cohen, Florida, Randazzese, and Walsh, 1998). Governments in many countries now view universities as key drivers of economic growth and critical for achieving global economic competitiveness (Laredo and Mustar, 2001).

Universities have been encouraged to improve their connections and research relevance to industry in order to advance commercial technologies and products (Lee, 1997; Cohen, Florida, et al., 1998). Thus, Science and Technology policy in the United States in the past forty years has aimed to promote collaboration between universities and industry through legislative reforms (e.g., Bayh-Dole Act, Economic Recovery Tax Act of 1981 and 1986; National Cooperative Research Act of 1984), subsidized partnerships (Behrens and Gray, 2001), funding requirements (Landry and Amara, 1998), and new research institutions (Cohen, Florida, Randazzeses, and Walsh, 1994b). These policies are based on the assumption that collaboration results in improved transfer of scientific knowledge and increased economic competitiveness through the development of innovative technologies (Behrens and Gray, 2001; Fluckiger, 2006), while decreasing the overall costs of innovation (Katz and Martin, 1997) by allowing facility and equipment sharing, as well as reducing duplication of research efforts.

In its most basic form, collaboration is simply two or more people working together to share intellectual, financial and tangible resources (Bordons and Goméz, 2000). However, this simple definition fails to capture the more complex and nuanced forms of collaboration. Collaboration runs through a continuum of work, from a small group of coworkers cooperating on a small project to large international ventures. In research, collaboration ranges from two colleagues working together in the same department to multinational research consortiums. Gray (1989b) defined collaboration as “a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible (p. 5). For Gray and her colleagues (Gray, 1989b; Gray and Wood, 1991; Wood and Gray, 1991), collaboration is a process. Bordons and Goméz (2000) concluded that collaboration is a social process, governed by the complexity of human relations and interactions. Thus, collaboration can be defined as a process or a culture through which individuals and organizations cooperate to address problems and accomplish goals that cannot be done as successfully by an individual.

Simply defining collaboration by the number of participants is not sufficient. The quality of collaboration can also differ substantially. Members of teams can choose to be either passive or collaboration participants in the collaboration process (Russo and Schoemaker, 1989; Roberto, 2005; Williams, Parker, and Turner, 2007, 2010). Collaboration participation tends to result in substantive collaboration, in which collaborators are actively involved in the fulfillment of the objectives of the team (Sawyer, 2007; Clark, 2009). Collaboration participation can be further divided according to the types of contributions that are made by team members (Sawyer, 2007): additive, exponential, and conceptual. Additive collaborations result when different team members contribute unique skills, knowledge, or resources. Exponential collaborations result when team members undertake different activities and aspects of a project, but use other team members to improve understanding and ideas. Conceptual collaborations result when the work of one researcher is founded on the work of other researchers. Though conceptual collaborations are foundational to scientific advancement and knowledge creation, the participants are not required to actively engage or communicate with one another. Sawyer contrasted substantive collaborations with symbolic collaborations, in which teams have members for honorary, social, or political reasons. Consequently, the quality and intensity of collaborations can differ significantly.

Effective collaboration and team work has been shown to have numerous benefits for both public and private organizations, including: improved transfer of knowledge, enhanced decision-making, improved innovation through the sharing and cross-pollination of ideas, reduced errors and costs, and cooperation across organizational units (Hensen and Nohria, 2004). In research, collaboration has been shown to improve the probability of acceptance of papers for publication (Bakanic, McPhail, and Simon, 1987) and to improve the citation rate of publications (Presser, 1980; Sauer, 1988). Collaboration is also one way for scientists to gain credibility and recognition from the academic community they belong to (Beaver and Rosen, 1978; Beaver, 2001). There are a variety of factors that have been shown to encourage collaboration among researchers. These include: getting access to additional resources, including equipment, facilities, data, and human capital; increasing academic publications; increasing the number of innovations; and improvement in the quality of teaching and employment opportunities for students (Landry and Amara, 1998). In addition, the complexity of scientific research encourages collaboration (Smith and Katz, 2000; Committee on Facilitating Interdisciplinary Research, 2004; Shrum, Genuth, and Chompalov, 2007) because there is no way for a single individual to acquire the knowledge and resources needed.

Nevertheless, collaboration also has costs which may make collaboration less effective and, even undesirable, in some situations. Individual workers and teams can become unproductive when collaboration becomes the goal, rather than a component of the process for accomplishing the goal (Hensen and Nohria, 2004; Hensen, 2009). For publicly funding research and development, excessive collaboration can actually be a distraction for researchers, particularly if researchers become focused on the applications and commercialization of their research, rather than the production of it (Cohen and Randazzese, 1996; David, 2000). Despite these potential drawbacks, collaboration has been shown to have significant benefits in innovation, decision-making, and research.

Although collaboration has been increasing in scientific fields in academia (Zuckerman, 1965; Beaver and Rosen, 1978), different disciplines have different cultures and standards for collaboration (Hirsch, 1968; Presser, 1980; Becher and Trowler, 2001; Newman, 2004; Belkhodja and Landry, 2007; Clark, 2009). Collaborative conventions are generally established during academic socialization in graduate school (Boyle, 1996; Ridding, 1996; Becher and Trowler, 2001). In some scientific fields, such as physics and biomedical sciences, large collaborative teams are common (Knorr-Cetina, 1999). In other fields, collaborative activities revolve around a few researchers working together (Zuckerman, 1965). In some disciplines, such as mathematics, collaboration is actually atypical (Newman, 2004). Collaboration with industry poses additional problems beyond crossing disciplinary boundaries. Private companies have different goals and orientations. Therefore, while collaboration in academia is more the norm now, working with industry is not.

Institutional Culture and Conventions

Organizational culture plays a critical role in establishing the standards and conventions for behavior for the members of an organization or group. The concept of culture was originally adopted by organizational researchers from cultural anthropologists who were studying whole societies (Schein, 1996a). Organizational culture became a useful concept for researchers trying to explain the relatively poor performance of American companies compared to Japanese ones (Schein, 1996a). Researchers proposed that the strength of the shared conventions in Japanese organizations led to superior performance in achieving organizational goals (Denison, 1990; Knapp, 1998; Ogbonna and Harris, 2001; Lai and Lee, 2007). Thus, organizational culture can provide a competitive advantage (Scholz, 1987; Lai and Lee, 2007). At the same time, a culture can provide obstacles to organizational change and reform.

The term ‘organizational culture’ typically covers a wide variety of concepts, ranging from the beliefs, values, and conventions an organization holds to its ideology, strategy, goals, managerial style and underlying operational assumptions (Schein, 1996a). Schein described an organizational culture as “the accumulated learning that a given group has acquired during its history… the patterns of basic assumptions invented, discovered, or developed” to help a group to make sense of the events, deal with problems, and to help new members determine how to understand, perceive, think, and feel about things of relevance to the group (Schein, 1996a, p. 7). Thus, organizational culture provides meaning, stability and comfort to the members of an organization because it influences perceptions and how things should be done (Hebb, 1954, 1955).

Often the assumptions underlying culture are unquestioned and implicit (Owens, 1987; Marcoulides and Heck, 1993; Schein, 1996a). As a consequence, organizational culture is a complex construct and researchers have had difficulty in precisely and empirically defining, measuring, and studying culture (Rousseau, 1990; Marcoulides and Heck, 1993; Schein, 1996a). Nonetheless, there is strong consensus that organizations have cultures and that these cultures influence conventions, behaviors, and priorities for the organization (Smircich, 1983; Schein, 1988; Alvesson, 1990; Hackett, 1990; Martin, 1992; Harris, 1994; Schein, 1996b, 1996a).

Universities, private firms, and government operations each have distinct cultures that determine how things get done and how success is measured. Private sector companies are primarily driven by owners seeking to maximize their return on investments. The profits of a firm are routinely distributed to the owners, who have assumed the risk of the success or failure of the business. Performance is measured quantitatively, typically through profits, market share, share price, earnings (Frumkin and Galaskiewicz, 2004). Businesses must necessarily focus on short-term financial success and tangible goals (Mueller, 2006), as there is no guaranteed long-term funding or cash-flow. The focus is on getting readily applicable knowledge that will assist the organization in meeting its goals (Mueller, 2006). Knowledge is, thus, viewed as an input to production (Brusoni and Prencipe, 2006). The cost and timeliness of the knowledge is crucial. Management is also viewed as a productive input (Perry and Rainey, 1988), contributing to the efficient use of resources.

Due to their profit maximization imperative, businesses will seek to acquire their resources as efficiently as possible. More successful firms will build relationships with their suppliers and customers to improve knowledge transfer and efficiencies (Schraeder, Tears, and Jordan, 2005), including to university researchers and students when these are viewed as production inputs. Innovation and research is often done on a team (i.e., collaborative basis) (Van de Ven, Polley, Garud, and Venkataraman, 1999; Chesbrough, 2003; Hargadon, 2003), then, both for timeliness and enhanced results.

Universities, on the other hand, are not beholden to a profit motive or limited by the need for timely results in the same way businesses are. They are loosely coupled bureaucracies, with shared decision making power and poorly defined power structures (Cohen and March, 1974). University organizations can seem much more disorganized and difficult to navigate and change.

Researchers within the public science system primarily undertake research for the purpose of knowledge creation and dissemination, mainly through publication of the results (Bozeman and Boardman, 2003; Whitley, 2003). Researchers follow their own research agenda. Researchers are primarily motivated by the pursuit of individual and organizational reputation and prestige within their academic disciplines (Whitley, 2003; Link and Siegel, 2005) and there is little concern with the commercial potential or post-discovery development. Most researchers have little patience with administration and accounting procedures (Bozeman and Boardman, 2003). Tenured faculty members enjoy lifetime employment (Dill, 1982) and are not generally concerned with the overall administration of the institution.

Though technology transfer and intellectual property exploitation have become part of the mission of many universities, university researchers and administrators typically have little incentive to accelerate the commercialization process. Researchers are not driven to meet externally imposed deadlines nor is scientific discovery a process that necessarily lends itself to a prescribed timeline (Kantorovich and Ne'eman, 1989; Kantorovich, 1993). Administrators want to ensure that they have followed all the appropriate rules and procedures to maximize the potential return on the intellectual property (Link and Siegel, 2005). Thus, there is a disconnect between the expectations and needs of private sector organizations and public sector ones.

There is no evidence that the increase in commercial activities at universities have yet affected the research culture so as to bias research towards industrial applications and away from basic discovery (Owen-Smith and Powell, 2003). However, the rapid pace of knowledge creation and the demands of the global marketplace have put pressures on public sector research organizations to adopt new roles in the innovation system.

The purpose of this dissertation is to explore the factors which lead academic researchers to cross the boundaries of academia to collaborate with industry. The focus is on the collaborative behavior and values of scientists and engineers in research universities. Furthermore, the institutional structure, academic culture and conventions, and research resources available to researchers in different academic departments are considered in order to differentiate individual from the organizational influences.

Specifically, the following research questions were addressed:

1. How are research scientists and engineers different with respect to their collaboration behavior and involvement with industry?

2. How do institutional factors and departmental research resources influence involvement of academic researchers with industry?
3. Does working with engineers influence scientists to be more involved with industry?

Dissertation Outline and Methodology

The dissertation is comprised of three essays. Each essay analyzes some aspect of the relationship of engineers and scientists, in order to examine the influence of academic discipline and institutional affiliation on the intensity of industrial involvement, as measured by the time spent working with industry, acting as a resource for industry, and actively collaborating with industry involvement.

The first essay investigates the differences between engineers and scientists with respect to their collaborative behavior, level of industry involvement, and their attitudes about external direction to their research. Engineers and scientists are trained differently; scientists are trained to make scientific discoveries, while engineers are trained to apply scientific knowledge to solve technical problems. The focus of policies on innovation, technology transfer, and the role of universities in the knowledge economy are premised on translating scientific discoveries into saleable products and services. That is, these policies are trying to link scientific discoveries by scientists with the problem-solving application expertise of engineers to spur private sector innovation. Unless there is an understanding of the differences between scientists and engineers and the barriers to interdisciplinary collaboration, these policies were unlikely to achieve their desired outcomes.

The second essay investigates the effect of research resources on the collaborative behavior and values of engineers and scientists. These resources include the human capital, financial resources, and physical capital available within one's own department, as well as the affiliation with University Research Centers (URCs). Studies of research and collaboration typically focus on either individual-level behavior (e.g., individual career paths, collaboration, publications and citations) or else aggregated institutional results (e.g., total institutional patents, total R&D expenditures, average institutional publications, average institutional citations per publication). These studies implicitly assume that institutional factors are homogeneous and that they affect individual researchers equally. However, the context of work and relationships matters. Departmental prestige, productivity, and resources are different within and across universities and thus, provide individual researchers with different influences, opportunities, and resources.

The third essay focuses on the effects that affiliation with a University Research Center dominated by different disciplines has on researchers. Specifically, the essay will consider whether scientists who are affiliated with URCs that are dominated by engineers exhibit different collaboration and industrial involvement patterns than scientists who are working primarily with other scientists.

The last chapter will conclude with a discussion of the overall results and policy implications. It will also discuss avenues for further study.

Data

The data used for this study were from two levels: the individual researcher and the department that the researcher resides in.

Data about the behaviors and attitudes of individual researchers comes from a survey done by the Research Value Mapping (RVM) Program[2], under the direction of Principal Investigator, Barry Bozeman taken between spring 2004 and spring 2005.[3]

The survey was designed to get a sample from the population of academic researchers in the STEM fields (i.e., science, technology, engineering, and mathematics) from research intensive universities. The RVM survey was designed to get responses from 200 men and 200 women in each of twelve STEM fields: Agricultural Sciences, Biological Sciences, Chemistry, Computer Science, Chemical Engineering, Civil Engineering, Earth and Atmospheric Sciences, Electrical Engineering, Materials Engineering, Mathematics, Mechanical Engineering, and Physics (Bozeman and Gaughan, 2007). The target population was identified through the departments and faculty listings at the Carnegie Doctoral/Research Universities (Research Value Mapping Program, 2005). The academic discipline that the doctorate was awarded in was identified by the researcher (Research Value Mapping Program, 2005). This was in turn coded with the NSF classification for academic fields. In addition to the specific fields, bivariate response variables were created for the aggregated categories of: (1) life scientists, (2) physical scientists, (3) engineers, (4) mathematicians and computer

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[2] http://www.rvm.gatech.edu/aboutrvm.htm

[3] The RVM project was based at the Georgia Institute of Technology in Atlanta, Georgia, and supported by the National Science Foundation and the Department of Energy.

scientists, and (5) other. An additional bivariate response variable for all scientists was created. For example, a researcher that identified that the PhD was awarded in microbiology was coded as a biologist for the academic discipline (NSF code 198) and as a life scientist, and more generally as a scientist. A researcher who received a PhD in civil engineering was classified as a civil engineer (NSF code 315) and as an engineer.

Questionnaires were sent to 4,916 tenure-track and tenured faculty members and a total of 1,795 usable surveys were returned for a response rate of 36.5 percent. Since the focus of the study was research scientists and engineers working in research-intensive universities, responses from scientists and engineers at Historically Black Colleges and Universities (HBCU), universities receiving additional federal R&D funding under the Experimental Program to Stimulate Competitive Research (EPSCoR) program, and responses from individuals outside of STEM fields (primarily sociology) were removed from the results. This left usable responses from 1,636 researchers, and an overall response rate of 33.3 percent. Of the responses, 770 (46.7 percent) were from scientists, 616 (37.7 percent) were from engineers, and 253 (15.3 percent) were from mathematicians and computer scientists. Appendix A contains more details about the RVM survey and the data.

Departmental level data were used to represent the institutional resources for research. Most department-level data were collected from the internet. There were 986 departments at 145 research universities that were represented in the survey. The NSF-IPEDS web site, Webcaspar,[4] provided data on the R&D and capital expenditures

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[4] https://webcaspar.nsf.gov/

and students and post-docs in the research fields. University endowments were obtained from the 2005 National Association of College and University Business Officers (NACUBO)[5] and from the annual report of the Chronicle of Higher Education.[6] University Library Rankings were obtained from the Association of Research Libraries.[7] Lastly, the National Research Council's most recent doctoral quality survey provided data on the number of faculty members, average publications per faculty member, average citations per faculty publication, and the percentage of faculty members with grants from 2005.[8]

Information about the academic disciplinary profiles for each of the University Research Centers was collected from the web or by contacting the Centers directly. For each URC, the number of faculty members affiliated with the center was counted and the discipline[9] of each affiliated faculty member was identified and recorded. The corresponding percentages of disciplines in the URC were then calculated[10] and the dominant discipline identified.

Information about the number of faculty members of the departments of each respondent was collected from the web or by contacting the Departments directly.

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[5] http://www.nacubo.org/documents/about/fy05nesinstitutionsbytotalassets.pdf

[6] http://chronicle.com/stats/endowments/

[7] http://www.arl.org/stats/annualsurveys/arlstats/index.shtml

[8] http://www.nap.edu/rdp/

[9] Five categories were used: (1) life sciences; (2) physical sciences; (3) engineering; (4) mathematics and computer science; (5) medicine; and (6) other.

[10] The percentages of faculty members were used to determine the academic discipline dominating the URC used in Chapter 4. So for instance, in a URC were there is 1 engineer and 9 life scientists, the URC would have 10 percent engineers and 90 percent life scientists, with the life scientists being the dominant discipline.

Industry Involvement

The core of the dissertation is the models testing individual and organizational factors on industrial involvement. Industry involvement can differ in both the quality and intensity of the relationship. Some forms of involvement require little time or effort, as for instance, when a researcher is asked about his research. This may be in the context of giving a presentation at an academic conference or in responding to telephone or email inquiries. Thus, this form of involvement may not actually require the researcher to alter his or her behavior or research activities. Other forms of involvement, such as directly working with industry on the development of commercial products, patents, or co-authoring papers, require a much greater commitment of time and energy to engage in. Thus, three types of industry involvement were tested in each of the essays:

1. Time spent working with Industry [INDTIME]
2. Likelihood of a researcher being involved with industry by acting as an interface with academia for industry [RESOURCE].
3. Likelihood of a researcher actively collaborating with industry [COLLAB].

Time Spent Working with Industry

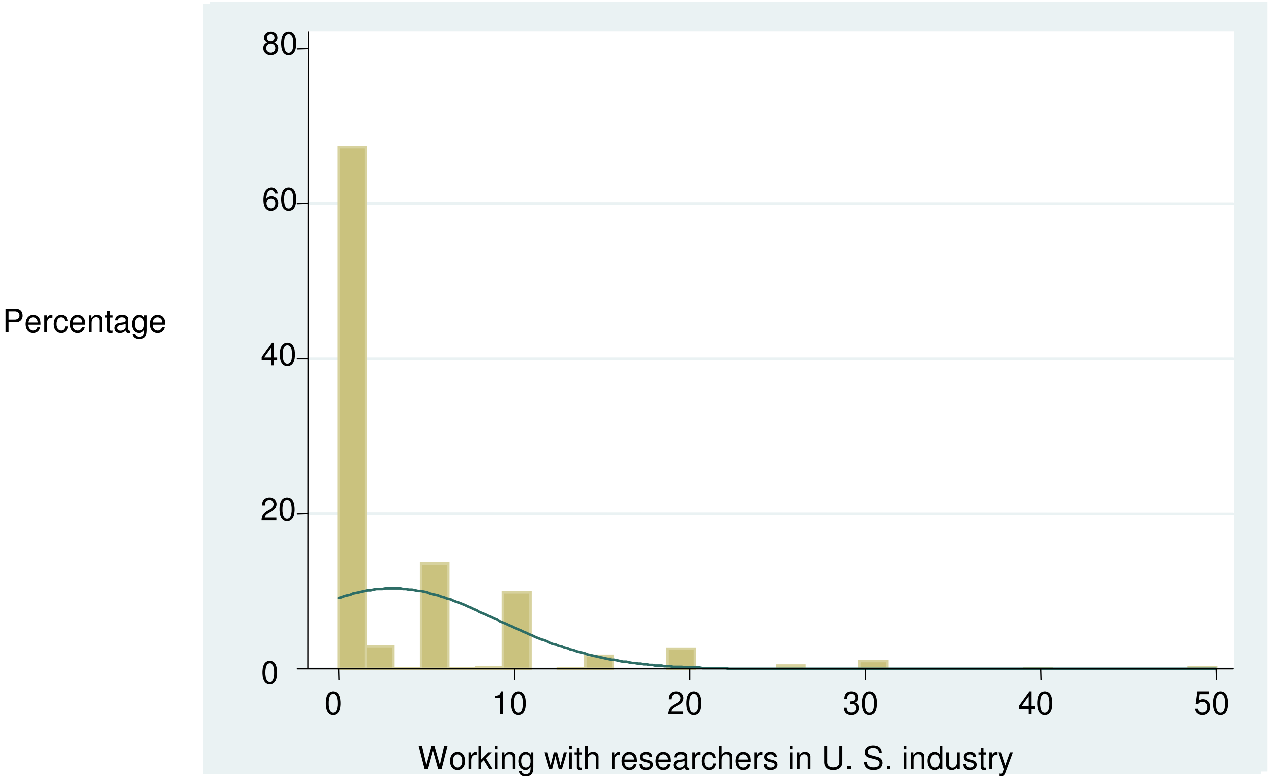
The first measure of industrial involvement is the total percentage of time that a researcher spends working with industry [INDTIME]. As shown in Table 1.1, only 34 percent of all researchers (556 researchers of the 1636) spend any time working with industry. For these researchers, disciplinary differences are noticeable. Approximately half of all engineers spent some time working with industry, while only 25.5 percent of scientists and 22.9 percent of mathematicians and computer scientists did. Chi Square tests indicated that the disciplinary differences are statistically significant. Disciplinary differences also exist in the average amount of time spent working. For scientists that spend some time working, an average of 8.3 percent of a researcher's time is spent working with industry. Mathematicians and computers scientists who collaborate with industry spend an average of 9 percent of their time with industry. Engineers spent slightly more time than any other discipline, with an average of 9.5 percent of their time spent working with industry for those engineers that do collaborate with industry.

Table 1.1 Time Spent Working with Industry

INDTIME	Obs	No time with industry (no.)	Some Time with industry (no.)	Some Time with industry (%)	Mean percentage of time for those who do collaborate (%)	Standard Deviation for time for those who collaborate (%)
Total	1634	1078	556	34.0	9.05	7.25
Scientists	770	574	196	25.5	8.31	6.96
Life Scientists	292	203	89	30.5	9.03	7.81
Physical Scientists	478	371	107	22.4	7.71	6.14
Engineers	612	309	303	49.5	9.53	7.16
Mathematicians and Computer Scientists	249	192	57	22.9	8.96	8.51

As a percentage measurement, the variable is bounded by 0 and 100, which makes an OLS regression model estimate both biased and inefficient because the variable is censored. In addition, the variable is heavily weighted with zeros, as shown in Figure 1.1.

Figure 1.1 Distribution of INDTIME Variable



There are two possible reasons for the reporting no involvement with industry. The first is that the individual did not have the opportunity to work with industry. The second is that the individual had the opportunity to work with industry but did not do so in the previous 12 months. These different reasons for the zero responses should be accounted for when developing a regression model. Simply rescaling the variable or transforming it, say for example into a log odds ratio, does not eliminate the clustering of responses.

Rather than simply being truncated, the distribution of the variable actually has two embedded distributions: the first is a bivariate model dominated by zeros and the second is a count model that is truncated at zero. Zero-inflated count models were developed to account for the excesses of zeros in data and to ensure that an under-prediction of zeros does not occur in the model estimation (Lambert, 1992; Cameron and Trivedi, 1998; Long and Freese, 2006). Two types of distributions can be used for the count portion of the model: Poisson and Negative Binomial. Poisson models constrain the data with the requirement that the expected mean, E[y], and variance, σ^2, are equal, contingent on the covariance. Negative binomial models are less restrictive with the variance, with the expected mean being less than the expected variance, dependent on the covariance. Post-estimation comparisons of the Poisson model, Negative Binomial model, Zero Inflated Poisson Models, and Zero Inflated Negative Binomial model indicated that a Zero Inflated Negative Binomial was most appropriate for this model.

Resource for Industry

The second variable used to examine industry involvement is a measure of the extent to which a researcher acts as a resource for industry [RESOURCE]. As a resource, a researcher is involved with industry in a way that does not require substantial changes in the activities or tasks of the researcher. That is, the relationship with industry allows the researcher to exchange information, provide services and expertise to industry, or to help students get employment in industry, but does not require the researcher to alter research goals, behavior, or values.

This variable is operationalized as the summation of five individual types of industry involvement: (1) whether a researcher has been asked for information about their research by a private company in the previous 12 months; (2) whether a researcher has contacted industry about their research or research interests in the previous 12 months; (3) whether a researcher has acted as a paid consultant for industry in the previous 12 months; (4) whether a researcher has placed a student with industry in the previous 12 months; and (5) whether a researcher has been involved in some other activity acting as a resource for industry, such as acting as an unpaid consultant or providing testing services for industry.

Over half of all researchers are not involved in any activity in which they act as a resource for industry, as shown in Table 1.2.

The most common resource activity is for a researcher to have been asked about their research. Approximately 27 percent of scientists have been asked about their research by a private company in the previous 12 months. Twice as many engineers (56.5 percent) had been asked about their research by industry. Mathematicians and computer scientists are the least likely to be asked about their research by industry representatives, with only 23.7 percent reporting this type of activity. Additionally, engineers were two and a half times more likely to have contacted industry about their own research than either scientists or mathematicians and computer scientists, with 31.4 percent of all engineers reporting having contacted industry in the previous 12 months versus 13.2 percent of scientists and 12.4 percent of mathematicians and computer scientists.

Table 1.2 Resource for Industry

RESOURCE	Number reporting	Total (n=1634) (%)	Scientist (n=770) (%)	Engineer (n=612) (%)	Math and CS (n=249) (%)
No RESOURCE activities	865	52.9	66.9	29.6	66.7
Researcher has been asked for information about their research by a private company in the previous 12 months	611	37.4	26.8	56.5	23.7
Researcher has contacted industry about their research or research interests in the previous 12 months	311	19.0	11.4	31.4	12.4
Researcher has acted as a consultant for industry in the previous 12 months	300	18.4	13.2	27.1	12.9
Researcher has placed a student with industry in the previous 12 months	414	25.3	14.7	42.2	17.3
Other resource activities, including lecturing at conferences, acting as an unpaid consultant, or sitting on a corporate board	81	5.0	4.2	5.7	5.6

Engineers are more likely to place students in industry than either scientists or mathematicians and computer scientists. Forty two percent of engineers reported placing students or post-docs with industry. Only 17 percent of mathematicians and computer scientists reported placing students, while fewer than 15 percent of all scientists reported placing students or post-docs with industry.

Engineers are twice as likely to act as consultants for industry than either scientists or mathematicians and computer scientists. Twenty seven percent of all engineers have been paid consultants for industry within the previous 12 months, while only 13.2 percent of all scientists and 12.9 percent of all mathematicians and computer scientists were paid consultants during the same period.

Figure 1.2 Distribution of RESOURCE Variable

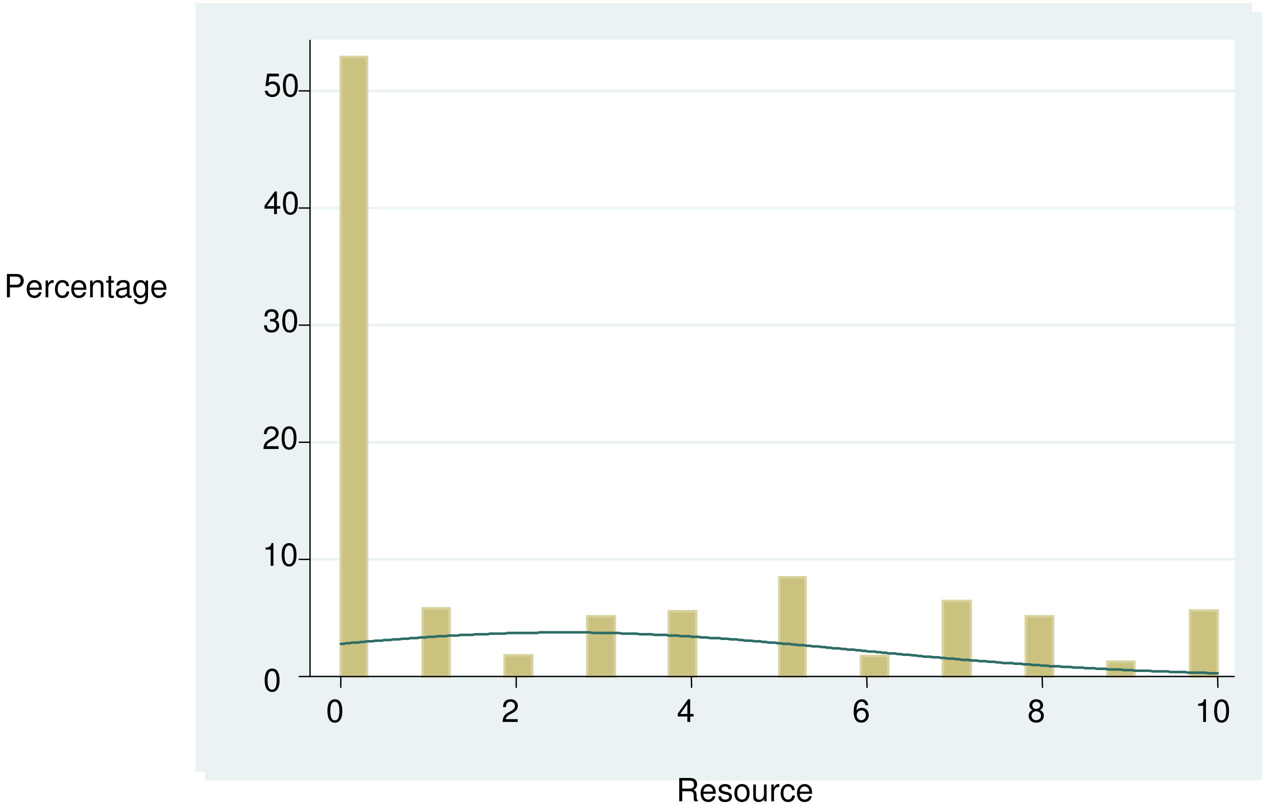


Figure 1.2 shows the distribution of the RESOURCE variable. Both the underlying binary variables and the resulting summation variable [RESOURCE], are dominated by zeros, as discussed above. That is, the majority of respondents did not identify themselves as being involved with industry for each of the underlying items. As with the time spent working with industry, these excessive zero responses must be

accounted for in the model. A Zero Inflated Negative Binomial model was used. Post estimation testing confirmed that this is the most appropriate model.

Active Collaboration with Industry

The last variable used to measure involvement with industry represents the extent to which a researcher is active collaboration with industry [COLLAB]. Active collaboration with industry requires some modification of behavior because it requires an interdependence of decision-making and outcomes (Gray, 1989a). Participants come together to find common ground and share their expertise in order to solve a problem or create new understanding. Five types of collaborative activities were identified: (1) whether a researcher has worked at a company in which the researcher is an owner, partner, or employee in the previous 12 months; (2) whether the researcher has worked directly with industry on work that has resulted in a patent or copyright protection in the previous 12 months; (3) whether the researcher has worked directly with industry in an effort to transfer or commercialize technology or applied research in the previous 12 months; (4) whether the researcher has co-authored papers with industry personnel in the previous 12 months; and (5) whether the researcher is collaboration with industry in some other way, including being funded by industry. Unlike activities in which a researcher acts as a resource for industry, collaborating with industry involves some loss of control over the research process for a researcher as the goals, objectives, and needs of other stakeholders must be considered and accommodated.

Most researchers do not engage with industry at all. Of the 1636 researchers in the survey, 1089 did not report participating in any of the collaboration activities. Over three-fourths of all scientists and mathematicians and computer scientists reported no collaborative activities. On the other hand, approximately half of all engineers indicated that they were involved in at least one collaboration activity. The disciplinary breakdown of collaborative activities is presented in Table 1.3.

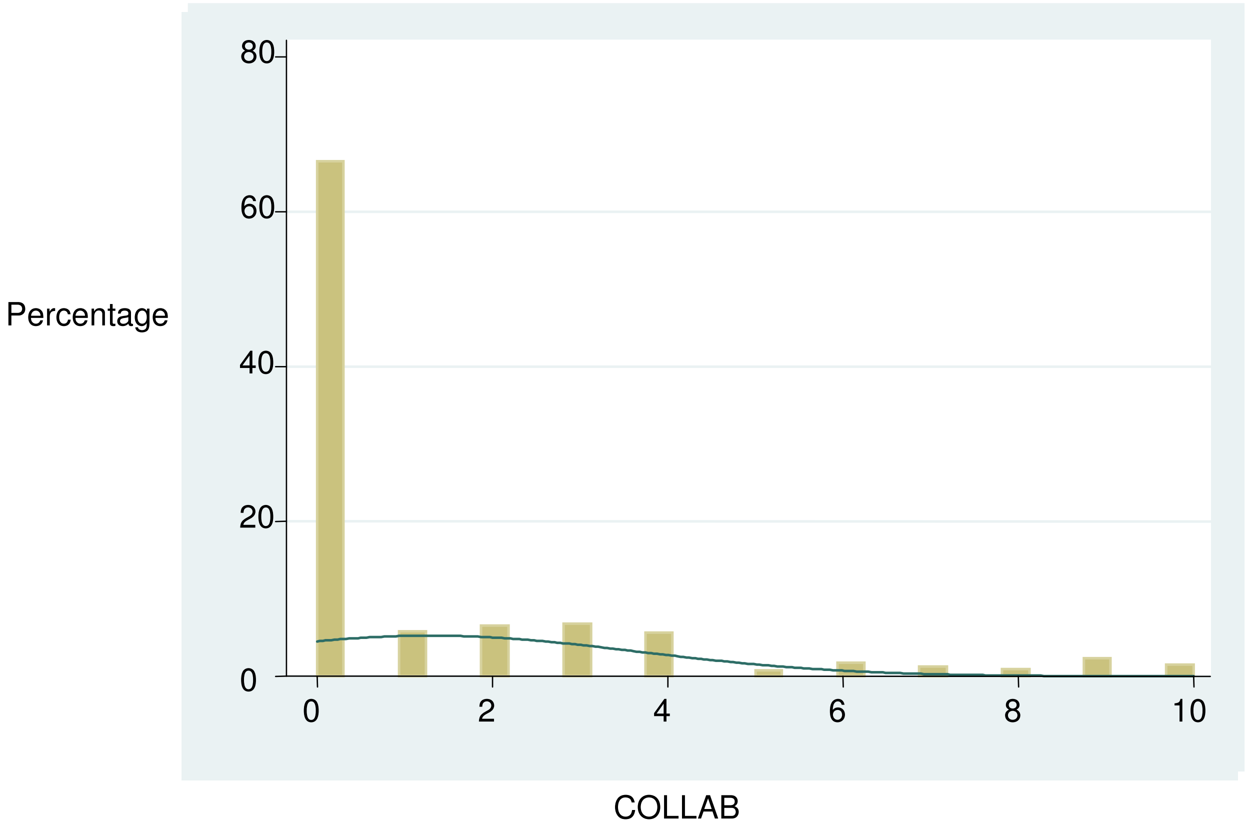
Engineers were twice as likely as either scientists or mathematicians and computer scientists to engage in commercialization efforts with industry, co-authoring publications, or being funded by industry. Approximately 20 percent of all engineers had participated in at least one of these collaborative activities. Few researchers have worked directly for or with a private company on patenting or copyrights. Nonetheless, engineers were three times as likely to engage in these activities. Nine percent of engineers reported working directly with industry on patents and copyrights, while only 3.6 percent of scientists and 2.4 percent of mathematicians and computer scientists had done this. Only 2 percent of mathematicians and computer scientists and 2.2 percent of scientists have worked directly for a company in which they had an economic interest. Approximately 6 percent of engineers, meanwhile, have worked directly for a company in the past 12 months, either as an owner, partner, or employee.

Table 1.3 Collaboration with Industry

COLLAB	Obs	Total (n=1634) (%)	Scientists (n=770) (%)	Engineers (n=612) (%)	Math and CS (n=249) (%)
No collaboration activity	1089	66.6	77.3	49.3	75.9
Researcher has worked at a company in which the researcher is an owner, partner, or employee in the previous 12 months	58	3.6	2.2	5.9	2.0
Researcher has worked directly with industry on work that has resulted in a patent or copyright protection in the previous 12 months	89	5.4	3.6	9.0	2.4
Researcher has worked directly with industry in an effort to transfer or commercialize technology or applied research in the previous 12 months	263	16.1	12.9	22.4	10.8
Researcher has co-authored papers with industry personnel in the previous 12 months	248	15.2	9.2	24.7	10.4
Researcher is collaboration with industry in some other way, including being funded by industry	209	12.8	7.4	20.4	10.8

Each of these is a bivariate response variable with respondents indicating whether they were or were not involved in the activity. While it would be possible to sum the responses to form a simple count variable, this would assume that each activity is equally difficult and common. Weighting the variables proportionally to the frequency of the occurrence of the activity allows the intensity and the diversity of the activities to be incorporated (Bozeman and Gaughan, 2007, see specifically page 702; Ponomariov, 2008; Clark, 2009). Thus, weights were created for each of the items in the collaboration variable. Each item was multiplied by the inverse of the percentage of respondents reporting collaboration with a particular activity. The relevant weighted items were then summed to create a weighted summation. The weighted sums were then classified on a scale of 0 to 10 using natural breakpoints in the weighting measures to create an ordinal variable. Thus, an increase on the scale indicates an increase in the diversity and intensity of the involvement in activities, rather than a simple count of the number of different activities a researcher is involved in. As with the variable measuring the extent to which a researcher acts as a resource for industry, the variable measuring the extent to which a researcher is actively collaborating with industry [COLLAB] is heavily dominated by zero responses, as shown in Figure 1.3. Thus, a Zero Inflated Count model was used to test the hypotheses that use this variable.

Figure 1.3 Distribution of COLLAB Variable



Chapter 2: The Differences between Academic Scientists and Engineers

Introduction

This chapter explores the influence of academic discipline on the research behavior of individuals. Specifically, the chapter will look at the effects on collaboration, industry involvement, and attitudes about research collaboration of academic researchers trained in the natural sciences (e.g., physics, chemistry, biology) and those trained in engineering.

Differences between Engineers and Scientists

While various studies have considered the role of academic disciplines in identifying problems, methodologies (Becher, 1989; Kekäle, 2002), professional socialization (Turner, Miller, and Mitchell-Kernan, 2002), and research conventions (Snow, 1964; Becher, 1981, 1989), the distinction between engineers and scientists is largely ignored by policymakers and administrators. Policymakers, managers, and researchers often lump science, engineering, and mathematics together as ‘STEM’ fields, and proceed to formulate incentives and requirements based on the assumption that training, socialization, and cultural differences are either not important or easily overcome. However, engineers, scientists, and mathematicians are all trained very differently, with different professional conventions, standards, and methods. They conceptualize research problems differently and seek understanding in line with their academic training. Therefore, failing to understand the professional and cultural barriers can actually result in ineffective policies.

Technology transfer efforts are founded on the belief that scientific discoveries can be leveraged to create products and services that have real world applications. These scientific discoveries are often viewed as coming from scientists, working alone in laboratories. The application of these scientific discoveries by engineers and technicians is believed to be relatively straightforward and not particularly noteworthy. However, the innovation process is not linear (Price, 1963, 1965; Kranzberg, 1967; Rosenberg, 1982; Wise, 1985; Zuckerman, 1988). Scientific innovation is complex and requires the cooperation and understanding of different disciplines, particularly if scientific knowledge residing in universities is to be leveraged more effectively and quickly.

Innovation and technology transfer policies often try to unite scientific discoveries by research scientists with the problem-solving application expertise of engineers to spur private sector innovation. Policies try to get scientists and engineers to collaborate with industry in the hopes that proximity will lead to commercial innovation. In addition, policymakers expect that multidisciplinary projects will result in greater innovation (Zare, 1997). Research has shown that there are substantial differences in the education, goals, values, culture, expectations and work styles of scientists and engineers (Danielson, 1960; Blade, 1963; Allen, 1988). These differences drive the professional conventions that engineers and scientists adhere to and actually create barriers to collaboration and industrial involvement. Policies that try to force collaboration without an understanding of the disciplinary barriers that need to be overcome and the rewards and incentives that drive researcher behavior may fail to promote interdisciplinary and industrial collaboration. Instead, scientists may continue to gravitate towards scientists, while engineers continue to favor working with other engineers. This reduces the likelihood of scientific research leading to tangible applications, which may ultimately result in public calls for research funding cutbacks. On the other hand, an increased knowledge of the potential barriers that exist can lead to more effective policies and administration of research collaboration and innovation.

Engineers and scientists are fundamentally different in terms of how they approach their jobs, the type and amount of supervision they require, the type of recognition they desire, their orientation towards industrial and research application, and their personality traits (Danielson, 1960; Allen, 1988).[11] They have different research styles and information needs (Pinelli et al, 1993). Scientists tend to gather information and test hypotheses, whereas engineers rely on more selective iterations to develop understanding and new knowledge (Vincenti, 1990). Traditionally, scientists have been concerned with discovering and explaining nature, whereas engineers have been much more focused on using their understanding to develop and make things (Blade, 1963;

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[11] For purposes of this paper, researchers were classified according to the discipline in which they received their PhD. Scientists include graduates from both life and physical scientists. Life science includes the disciplines of biology, biochemistry, oceanography, agricultural science, and psychology. Physical science includes physics, geology, earth and atmospheric sciences, and astronomy. Engineers are classified as individuals who graduated with a PhD in any engineering discipline, including computer engineering. Though material science could be classified as either a science or engineering discipline, it is most often coupled with metallurgical and material engineering and is classified as an engineering discipline. Similarly, individuals with degrees in computer science are coupled with mathematicians, while those with computer engineering degrees are included with engineers, even if the curriculum of these programs differs little.

Ritti, 1971) . In other words, scientists are focused on the discovery process and engineers are focused on the application process.

Since engineers and scientists have different group conventions, there would be an expectation of different behaviors by individuals who identify themselves (and value) membership in these different groups. On the other hand, institutional theory would predict that institutional pressures for conformance to the standards of the organization in an effort to achieve institutional legitimacy (DiMaggio and Powell, 1991) and prestige (Brewer, Gates, and Goldman, 2002; Weisbrod, Ballou, and Asch, 2008), might force convergence of values and behavior, as individuals attempt to integrate into the academic culture of a research university.

One of the problems with much of the past research on engineers and scientists is that it often compared scientists with PhDs to engineers with baccalaureates (Allen, 1988; Kennedy, Pinelli, Barclay, and Bishop, 1997) or it classified “scientists” as individuals working on scientific research and “engineers” as individuals collaboration in the application of scientific principles and methodologies in non-research environments, regardless of disciplinary affiliation (see for example Holmfeld, 1970). Thus, it is difficult to know if differences are a result of varying levels of education and whether the socialization process in getting a doctoral degree results in greater convergence in values and work than would be expected based on previous research. Though more recent research has acknowledged the differences between scientists and engineers (see for example, Boardman and Ponomariov, 2007; Clark, 2009; De Grip, Hall, and Smits, 2010), the implications of these differences are often left unexplained. Studying the differences in attitudes, values, and work styles of scientists and engineers with

PhDs may provide some insight as to whether greater congruence occurs with increased education and academic socialization. In addition, it provides a baseline for understanding the culture and disciplinary differences that may make interdisciplinary collaboration and knowledge transfer difficult.

Hypotheses: Behavior and Values of Research Scientists and Engineers

Though the differences between engineers and scientists are well established in the literature in terms of their culture, conventions, orientations, methods, and goals, this does not necessarily translate into different levels of involvement with individuals, activities and organizations outside of academia. However, there is strong evidence that this may be the case.

Table 2-1: PhDs in Academia by Academic Field

Discipline	Total PhDs (%)	Faculty (%)	PhD graduating 2005 (%)
All fields	100.0	100.0	100.0
Science	78.6	83.4	37.0
Life	*40.6*	*42.2*	*27.0*
Physical	*18.2*	*14.3*	*10.0*
Health	*4.2*	*5.5*	*1.9*
Engineering	17.1	11.1	14.8
Math and Computer Science	6.9	8.5	5.4
Social Sciences	12.9	18.5	40.9

SOURCE: National Science Foundation, FY2006.

Overall, PhDs in science comprise 78.6 percent of all PhDs and 37 percent of the PhD graduates in 2005, as shown in Table 2.1. Scientists make up 83.4 percent of university faculty membership. On the other hand, engineers make up 17.1 percent of the population of PhDs, but comprise only 11.1 percent of university faculty.

In contrast, PhD engineers are much more likely to go work for industry when they graduate. The majority of engineering PhDs (55.44 percent) work in industry, shown in Table 2.2. In contrast, only 26.4 percent of PhDs in science work for industry, though this ranges from a low of 18.3 percent for graduates in health-related field to 42.9 percent for graduates in the physical sciences. PhDs in life science, health-related fields, math and computer science, and the social sciences are far more likely to remain in academia after graduation than to work in any other sector.

Table 2-2: PhD Employment Sector by Academic Field

Discipline	Overal l (%)	Faculty (%)	Industry (%)	Nonprofit (%)	Govt (%)	Self-employed (%)
Science	100.0	46.31	26.40	6.68	9.49	6.97
Life	100.0	45.32	22.72	7.68	10.12	9.75
Physical	100.0	34.20	42.94	6.19	9.58	3.62
Health	100.0	56.84	18.32	8.53	9.14	4.11
Engineering	100.0	28.38	55.44	3.45	7.38	4.19
Math and Computer Science	100.0	53.99	31.67	3.60	5.05	3.20
Social Sciences	100.0	62.47	11.79	5.82	9.76	4.97

SOURCE: National Science Foundation, FY2006.

In addition to employment, research expenditures are another way to appraise values and orientation towards industry. Research funding can be used to assess the relative immediacy of the work of academic researchers with respect to industrial needs. Industry is generally more interested in the results of their research investment and grants, rather than in the scientific process itself or the advancement of knowledge (Matkin, 1990). Industry funds approximately 67.4 percent of all research and development in the United States and the federal government funds about 26.1 percent (NSF, 2008b). However, the distribution of funding is not even across all types of research. Industry funds about 84.1 percent of development, but only 17.7 percent of basic research (Please see Table 2-3 for amounts of R&D funding and Table 2-4 for percentage distribution of funding) (NSF, 2008b).

Table 2-3: Funding Sources and Amounts (in millions) to Types of Research

Type of Research	Federal Government	Industry	Other	Total
Total	$ 103,709	$ 267,847	$ 26,073	$ 397,629
Basic	$ 39,379	$ 12,222	$ 17,545	$ 69,146
Applied	$ 28,661	$ 53,758	$ 6,172	$ 88,591
Development	$ 35,669	$ 201,798	$ 2,424	$ 239,891

SOURCE: National Science Foundation, FY2008.

Table 2-4: Funding to Different Types of Research

Type of Research	Federal Government (%)	Industry (%)	Other (%)	Total (%)
Total	26.1	67.4	6.6	100.0
Basic	57.0	17.7	25.4	100.0
Applied	32.4	60.7	7.0	100.0
Development	14.9	84.1	1.0	100.0

SOURCE: National Science Foundation, FY2008.

On the other hand, the federal government funds 57.0 percent of basic research, but only 14.9 percent of development (NSF, 2008b). Industry funding is clearly focused on applied research and development; that is, on the portion of the innovation process that is more closely linked to commercial application of research.

Table 2-5: Funding Sources and Allocations

Field	Total (%)	Federal funding (%)	Other funding (%)
Life sciences	60.13	59.76	60.70
Psychology	1.79	2.04	1.41
Environmental sciences	5.39	5.85	4.71
Physical sciences	7.58	8.77	5.77
Engineering	15.33	15.07	15.72
Mathematical sciences	1.20	1.43	0.85
Computer sciences	2.83	3.30	2.12
Social sciences	3.74	2.59	5.47
Total funding	100.0	100.0	100.0

SOURCE: National Science Foundation/Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY2008.

Basic research in the United States is primarily done in research universities, funded largely by the federal government. Of the $69.15 billion spent on basic research in the United States in 2008, $38.82 billion, or 56.5 percent, was performed by higher education institutions (NSF, 2008b). Since the mid-1970s, industry-university research has expanded substantially, though industrial support still only accounts for about 7 percent of university research funding (NSF, 2008a). Industry funding of research is generally focused more on fields perceived to be performing more applied research and development. (Please see Table 2-5 for the funding sources and allocations to various academic fields.)

For example, engineering fields accounted for 15.3 percent of total research expenditures at universities. However, non-federal sources of funding accounted for a slightly greater proportion of engineering funding, while the federal government accounted for slightly less. Approximately 15.1 percent of all federal funding was allocated for engineering, while 15.7 percent of all non-federal funding went to engineering, indicating that non-federal sources of funding disproportionately funded engineering research.[12] This also holds true for research in the life sciences and, surprisingly, the social sciences. On the other hand, the federal government funded a greater share of computer science, environmental science, mathematical science, physical science, and psychology.

In a study of industry's use of research, the most relevant research was from engineering and applied science, rather than from basic science (Klevorick, Levin, Nelson, and Winter, 1995). Therefore, it is expected that industry will seek out academic researchers who have the greatest likelihood of providing industry-applicable results from their research. As engineers generally have greater interest in the application of their research to "real-world" problems, it is expected that engineers will have a greater likelihood of being involved with industry.

Though research has shown that collaboration is increasingly important in scientific research (see for example, Beaver and Rosen, 1978, 1979; Katz and Martin, 1997; Beaver, 2001, 2004), these studies are far from conclusive about the disciplinary effects on the amount of time spent working. In their study of scientific collaboration in publications, Beaver and Rosen (Beaver and Rosen, 1979) found that the intensity of

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[12] If this were not the case, non-federal funding and federal funding would both be proportionally equal to the combined allocation of 15.07% to engineering fields.

collaboration was greatest in the biological sciences, with engineers trailing behind chemists and physicists in the frequency of their collaboration. On the other hand, engineers have strong disciplinary conventions to work together. Engineers more frequently collaborate and informally share knowledge in the course of doing their work (Belkhodja and Landry, 2007). In solving problems, engineers are more likely than scientists to rely on personal communication and experience (Kaufman, 1983; Pinelli, Bishop, Barclay, and Kennedy, 1993). In contrast, scientists are more likely to rely on written communications (via journal articles and library searches) in their research (Allen, 1977; Kennedy, Pinelli, et al., 1997). Therefore, it is expected that engineers will spend more time collaboration in communication and collaboration during their research since engineers are generally more dependent on informal communication in their work. Due to the nature of their academic training and work style, therefore, it is expected that engineers will spend a greater amount of time working with industry than scientists.

H1-1: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to spend time working with industrial personnel.

One of the common distinctions between scientists and engineers is the goal of the work. Scientists are believed to be focused on producing knowledge, whereas engineers are focused on producing physical designs, products, and processes (Matkin, 1990; Kennedy, Pinelli, et al., 1997). Engineering is typically conceived of as the development or improvement of some technology through the application of scientific knowledge (Kemper and Sanders, 2001). Thus, engineers are considered to have a greater interest in applied research than scientists. In addition, they are more likely to be interested in achieving the goals of organizations that they belong to (Ritti, 1968, 1971; Kennedy, Pinelli, et al., 1997) and in creating something useful (Matkin, 1990).

In a study of graduate students, Becker and Carper found that engineers were not influenced by the socialization process of graduate school in the same way that students studying other disciplines were (Becker and Carper, 1956). Engineers maintained a strong attachment to the profession of engineering, and continued to maintain the belief that they could leave academia for the private sector at any point. Miller and Wager (Miller and Wager, 1971) found that engineers and scientists had significantly different responses to organizational socialization, with engineers responding more favorably to organizational goals, whereas scientists were more aligned with their disciplinary profession and valued professional autonomy. Engineers are generally interested in applying scientific principles to solve technical problems (Blade, 1963), rather than seeking to understand scientific principles merely for interest (Matkin, 1990). This would seem to make them more responsive to external problem demands.

The applied nature of engineering work means that engineers tend to have values and goals more convergent with industry’s goals and short-term time horizon than other fields (Belkhodja and Landry, 2007). Engineers are more likely to be involved with industry (Bozeman, 2009). Thus, it is expected that engineers were more involved with industry because this provides an avenue for solving applied technical problems.

Industry involvement can differ in both the quality and intensity of the relationship. Some forms of involvement require little time or effort, as for instance, when a researcher is asked about his research. This may be in the context of giving a presentation at an academic conference or in responding to telephone or email inquiries. Thus, this form of involvement may not actually require the researcher to alter his or her behavior or research activities. Other forms of involvement, such as directly working with industry on the development of commercial products, patents, or co-authoring papers, require a much greater commitment of time and energy to engage in. Thus, two types of industry involvement were tested. The first is the likelihood of a researcher being an interface with academia by acting as a resource for industry. The second is the likelihood of a researcher actively collaborating with industry. In both cases, it is expected that engineers will exhibit a greater likelihood of being involved with industry.

H1-2: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to be an interface or resource for industry, including providing information about research advancements, placing students with industry, and serving as a consultant to industry.

H1-3: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to actively collaborate with industrial personnel in technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry.

Engineering work involves the application of scientific knowledge to solve problems. Thus, engineers engage not only with researching, experimenting, scientific and mathematical analysis, and publishing, but also with designing, drafting, building and testing prototypes, technical communication, marketing, and project management (Ritti, 1971). Engineering, by its very nature, is applied and relies on the application of understanding to physical problems. On the other hand, engineers can exhibit the same passion, determination, and adherence to paradigms that other disciplines do, despite the applied nature of their work (Constant II, 1980).

In an extensive study of scientists and engineers in industry, Ritti (1971) found that while both scientists and engineers valued career advancement and development, their orientations and expectations for advancement were different. Scientists were oriented much more strongly to their professional associations and to assessments by their peers. Engineers, in contrast, tied their career progress much more tightly to the organization where they were employed. Ritti also found that engineers valued professional autonomy much less than did scientists.

For engineers, their focus on real world applications, rather than merely theoretical research, and their professional orientation towards identification with the goals of the organization with which they are affiliated is expected to translate into engineers having more favorable attitudes towards external direction of their research.

H1-4: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to believe that research funding decisions should emphasize the application of the research for the benefit of society over the researcher's own intellectual curiosity.

Dependent Variables and Methodology

The descriptive statistics for the dependent and independent variables are presented in Table 2.6. The total percentage of time that a researcher spends working with industry [INDTIME] is used as the dependent variable to test the first hypothesis, H1-1. As detailed in Chapter 1, the variable is heavily weighted with zeros and a Zero Inflated Negative Binomial model was used.

H1-2 tested the extent to which a researcher acts as a resource for industry. The Industrial Resource variable discussed in Chapter 1 [RESOURCE] was used in a Zero Inflated Negative Binomial model.

The dependent variable for hypothesis H1-3 was the extent to which a researcher actively collaborates with industry [COLLAB], discussed in Chapter 1. A Zero Inflated Negative Binomial model was used to account for the heavy weighting of zeros.

Explanatory and Control Variables

The key explanatory (or independent) variable of interest is whether the researcher is a scientist or engineer [ENGINEER]. Only scientists and engineers were used in the model, resulting is 1384 total observations being included in the model – 772 scientists and 612 engineers. Academic discipline has been shown in previous research to influence the behavior and values of academic researchers (Clarke, 1964; Meadows, 1974; Hargens, 1975; Frame and Carpenter, 1979; Stefaniak, 1982; Avkiran, 1997; Beaver, 2001; Garg and Padhi, 2001; Liang, Kretschmer, Guo, and deB. Beaver, 2001; Wagner-Döbler, 2001; Moody, 2004; Gulbrandsen and Smeby, 2005; Toomela, 2007; Clark, 2009).

Control variables for the years since the PhD was awarded [YEARSPHD], whether the researcher has been awarded tenure [TENURE], whether the individual is supported by either government grants [GOVGRANTS] or industry grants [INDGRANTS], marital status [MARRIED], number of children [CHILDREN], whether the

Table 2.6: Descriptive Statistics

Variable Description	Freq	Mean	Std Dev	Min	Max
Percentage of total research time spent working with industry [INDTIME]	1382	3.270	6.094	0	50
Researcher acts as a resource for industry [RESOURCE]	1384	2.689	3.346	0	10
Researcher is active collaboration with industry [COLLAB]	1384	1.372	2.439	0	10
Intellectual curiosity should be much less important than potential benefit to society in research funding decisions [BENEFIT]	1326	2.241	0.823	1	4
Scientist [SCIENTIST]	772	0.558	0.496	0	1
Life Scientists [LIFE]	292	0.442	0.496	0	1
Physical Scientist [PHY_SCI]	480	19.119	11.216	2	57
Engineer [ENGINEER]	612	0.697	0.459	0	1
Number of Years since the PhD was awarded [YEARSWITHPHD]	1372	19.119	11.216	2	57
Tenure [TENURE]	964	0.697	0.459	0	1
Married [MARRIED]	1153	0.855	0.352	0	1
Number of children living at home [CHILDREN]	644	0.864	1.117	0	10
US Citizen [USCITIZEN]	981	0.708	0.454	0	1
Affiliated with a University Research Center [CENTAFF]	566	0.409	0.492	0	1
Female [FEMALE]	691	0.499	0.500	0	1
Government Grants [GOVGRANT]	658	0.475	0.499	0	1
Industry Grants [INDGRANT]	107	0.077	0.267	0	1
Engineer with industry Grant [ENGINDGRANT]	75	0.054	0.226	0	1

researcher is a native U.S. citizen [USCITIZEN], and whether the researcher is affiliated with a university research center [CENTAFF] will all be included in the model. These variables have all been shown in previous research to impact collaboration, behavior, and research values.

In much past research, age has been used as a proxy for both experience and physical age (Clark, 2009). In a study of academic researchers in computer science in China, Liang and his colleagues (Liang, Kretschmer, et al., 2001) found that age was negatively correlated to collaboration. That is, younger scholars were far more likely to collaborate than older ones. Older scholars have also been found to be less productive on average than younger ones (Kyvik, 1990; Levin and Stephan, 1991; Smeby and Try, 2005), publishing less. However, this varies by discipline. Kyvik (1990, p. 50) found that productivity peaked in their 30s for researchers in physics, chemistry, and biology and in the 40s in mathematics, geosciences, biomedicine, clinical medicine, and odontology, and in the 50s for researchers in social medicine. Levin and Stephan (1991) found that publications in physics and earth sciences peaked in the 40s, while publications for researchers in geophysics peaked much later in the 50s.

Two possible measures can be used to control for experience and age. For experience, the number of years since the PhD was awarded can be used [YearswithPhD]. As a count measure, [YearswithPhD] is calculated as the year the survey was taken (2005) minus the year the PhD was awarded. When the year the PhD was awarded was unreported, a missing value was recorded. The missing value for the year the PhD was awarded may either indicate that no PhD degree has been received or that the individual did not report the year the PhD was awarded (whether inadvertently or not). This happened in 41 cases. Online searchers allowed the year the PhD was awarded to be filled in for 29 observations, bringing the number of missing cases to 12. Five of these were confirmed as not having a doctorate degree, while the other 7 did have doctorate degrees but no information about when the doctorate degree was awarded could be found. The year the individual was born, used to calculate age was also unreported occasionally, with 54 individuals not reporting, slightly more than those who did not report for the PhD year. Many of values for year born and the year the PhD was awarded were missing concurrently, indicating that there may be a non-random cause of the nonresponse. There is a very high correlation between age and the number of years since the PhD was awarded (0. 9406). However, using the Years since the PhD was awarded [YEARSWITHPHD] allows the effect of this nonresponse to be minimized. Since the intent of this variable is really to represent the experience and age of the researcher, the number of years since the PhD was awarded was used for the models in this dissertation.

Tenure status and academic rank have both been shown to delineate different behavior and values (Long, Allison, and McGinnis, 1993; Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007).[13] Tenured faculty are more likely to collaborate than non-tenured faculty (Piette and Ross, 1992). Researchers that have achieved tenure typically have developed greater social capital and larger professional networks on which to draw upon than non-tenured faculty (Bozeman and Corley, 2004). In addition, tenured faculty tends to be more productive than non-tenured faculty (Trow

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[13] Tenure and productivity are necessarily correlated since aspiring academics who cannot demonstrate at least a minimum level of acceptable academic productivity will not earn tenure. Academics with tenure have, thus, necessarily demonstrated the required that they meet the threshold level of academic productivity.

and Fulton, 1975; Blackburn, Behymer, and Hall, 1978; Knorr, Mittermeir, Aichholzer, and Waller, 1979; Kyvik, 1991). Tenure is measured as a bivariate variable with 1 indicating that tenure has been received.

Grants provide researchers with financial resources to support their research. Funding helps researchers to purchase equipment, fund graduate students, and buy-out from teaching responsibilities (Cortés, 1998; Durfee, 1999; Fairweather and Beach, 2002). Therefore, grants can have significant impacts on behavior and outcomes of research. Whether a researcher is funded by government grants is identified by a bivariate response variable, with a 1 indicating that the researcher is supported by a governmental research grant. The majority of researchers acknowledged having some form of grant funding (82.1 percent). Only 742 researchers (45.4 percent) identified that they had government grants. This result is somewhat misleading since most researchers did not recognize grants from the National Science Foundation (NSF) and National Institutes of Health (NIH) as government grants. If these grants are included as government grants, then 1266 (77.4 percent) of researchers received government grants. Thus, government grants in the models were taken to be consistent with the researchers' identification as grants from government entities outside of the peer-review allocation processes used by the NSF and NIH.

Likewise, whether a researcher receives funding through industry is identified by a bivariate response variable [INDGRANT] were included for the models testing H1-1 and H1-4. It was necessary to exclude this from the models testing H1-2 and H1-3, however, since funding from industry is a component of industrial involvement and, thus, is endogenous with the dependent variable. In addition, a variable was added to the models for H1-1 and H1-4 to account for any interaction effect for engineers that have industrial grants [ENDINDGRANT].[14]

Family relationships have been shown to influence researcher productivity. Marriage has been shown to enhance productivity (Long, 1990), while children have been shown to decrease productivity for women (Long, 1990). Whether the researcher is married is indicated with a bivariate response variable with 0 indicating the researcher is not married and 1 that he or she is married [MARRIED]. The influence of children is controlled for with a count variable indicating the number of children [CHILDREN] that a researcher has currently living at home.

Native-born researchers exhibit different patterns of research, collaboration, career advancement, and productivity than foreign-born researchers (Miller, 1992; Kang, 1996; Tang, 1997; Nerad and Cerny, 1999; Lee, 2004; Su, 2010). In his study of foreign-born versus native-born academic researchers, Sooho Lee (2004) found significant differences in collaborative behavior and productivity. Foreign-born researchers spent significant less time working than native-born researchers (78 percent of their time for foreign-born researchers versus 86% for native-born researchers). Furthermore, foreign-born scientists generally have fewer collaborators. However, Lee's research did show that foreign-born scientists are significantly more productive than native-born researchers. Foreign-born researchers published an average of 3.7 journal articles per year since graduation, whereas native-born researchers published fewer than 3.0 journal articles on average. Native U.S. citizenship [USCITIZEN] was used to distinguish native-born scientists from foreign-

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[14] ENGINDGRANT is excluded from models 2 and 3 because industry grants are a component of the construct for the dependent variables.

born ones. This is a bivariate variable with 1 indicating that the researcher is a native-born U.S. citizen.

University Research Centers (also known as University-Industry Cooperative Research Centers, Research Institutes, Engineering Research Centers, and associated names) are alternative institutional structures established in universities to promote behaviors that are less supported through the traditional disciplinary-based departmental structure (Geiger, 1990; Bozeman and Boardman, 2003). In addition, URCs provide access to resources – human, financial, physical – that are not available within an academic department (Bozeman and Boardman, 2003; Autio, Hameri, and Vuola, 2004; Tether and Tajar, 2008). Numerous studies have shown that affiliation with a university research center influences the behavior and values of individual academic researchers (see for example, Geiger, 1990; Guston, 2000; Bozeman and Boardman, 2003; Corley and Gaughan, 2005; Boardman, 2006; Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Boardman and Corley, 2008; Clark, 2009; Bozeman and Boardman, 2010; Ponomariov and Boardman, 2010). The variable for center affiliation [CENTAFF] was coded as a bivariate response, with 0 indicating that there was no center affiliation and a 1 indicating that the individual was affiliated with a university research center.

Females are a significantly smaller portion of the population of academic scientists and engineers, particular at the senior levels. Gender has been shown to influence collaborative behavior, though not in consistent ways. Some researchers have shown that gender positively influences the likelihood to collaborate (Corley and Gaughan, 2005), while others have found that female researchers are less likely to collaborate (see for example, Hagstrom, 1965; Long and McGinnis, 1981; Clark, 2009). Women have also been found to be less productive (Kyvik and Teigen, 1996; Fox, 2001) and far less likely to be promoted than men (Long, Allison, et al., 1993; Corley and Gaughan, 2005), even when controlling for levels of publications and age. These differences are likely to influence the values and research behaviors of women. Thus, it is crucial to ensure that the gender effects caused by the survey design intended to oversample women be properly accounted for. Weighting the samples is actually preferable to only including a binary response variable that accounts for the different responses between males and females since the goal is to be able to draw inferences to the larger population of scientists. Thus, the models in this dissertation will all be weighted to account for the disproportionate sampling of women that was done in the research design. A more detailed description of the gender and rank sampling and weighting requirements is found in Appendix A. A variable for female [FEMALE] were included in the model to test for the effects of being female.

The RVM survey was designed to draw a random sample of scientist, engineers, mathematicians, and computer scientists from the Carnegie Research Universities (Research Value Mapping Program, 2005). Department data were used to identify the target population. Therefore, all models were clustered by department in order to account for in department communalities which may result in observations from the same department having systemic heterogeneity in the error terms.

Results

Table 2.7 presents the results of the regression models. For the ZINB models used to test H1-1, H1-2, and H1-3, the marginal effects with unstandardized coefficients are presented. For the ordered logit model used to test H1-4, the regression results are presented. Marginal effects were calculated as the average marginal effects [AME], computed by taking the average of the partial changes over all observations. Dummy variables were explicitly identified in the estimation. This leads to more realistic marginal effects compared to using the marginal effects taken at the sample means [MEM] since the sample means may be nonsensical, particularly for dummy variables (Bartus, 2005). Interpreting marginal effects for nonlinear models is more difficult than with linear models (Cameron and Trivedi, 2009). Nonetheless, the direction and magnitude of the marginal effects are important properties for indicating and interpreting the relationships.

Overall, the empirical results show support for all four of the hypotheses. Being an engineer has a positive effect on the time spent collaborating with industry, industrial involvement, and greater acceptance of the applicability of research for the benefit of society in funding decisions.

H1-1: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to spend time working with industrial personnel.

Table 2.7: Regression Results

	INDTIME (zinb)	RESOURCE (zinb)	COLLAB (zinb)	BENEFIT (ologit)
Engineer [ENGINEER]	1.786 *** [0.488]	1.700 *** [0.291]	0.735 *** [0.176]	0.915 *** [0.196]
Number of Years since the PhD was awarded [YEARSWITHPHD]	-.018 [0.027]	-0.017 [0.011]	0.003 [0.009]	-0.007 [0.010]
Tenure [TENURE]	0.561 [0.345]	0.405 * [0.220]	0.063 [0.077]	-0.234 [-1.000]
Industry Grants [INDGRANT]	3.226 * [1.920]			0.184 [0.484]
Government Grants [GOVGRANT]	-0.143 [0.257]	-0.055 [0.090]	0.171 ** [0.072]	-0.209 [0.159]
Married [MARRIED]	0.114 [0.257]	0.076 [0.189]	0.019 [0.088]	0.354 [0.285]
Number of children living at home [CHILDREN]	-0.013 [0.482]	-0.001 [0.043]	0.016 [0.019]	0.016 [0.059]
US Citizen [USCITIZEN]	0.482 ** [0.229]	0.404 ** [0.183]	0.152 * [0.079]	0.098 [0.168]
Affiliated with a University Research Center [CENTAFF]	0.431 ** [0.206]	0.594 *** [0.166]	0.296 *** [0.102]	0.086 [0.164]
Female [FEMALE]	-0.238 * [0.124]	-0.205 ** [0.090]	-0.068 * [0.041]	-0.121 [0.157]
Engineer with Industry Grant [ENGINDGRANT]	-0.480 ** [0.206]			-0.155 [0.575]
Observations	1337	1339	1339	1298
McFadden's Adjusted R^2	0.049	0.057	0.062	0.021
Cragg-Uhler (Nagelkerke) R^2	0.627	0.697	0.641	0.076
Robust Standard Errors in Brackets * significant at 10%; ** significant at 5%; *** significant at 1%				

The first model evaluated the time spent working with industry. As expected, the results indicate that engineers are more likely to spend time collaborating with industry, confirming hypothesis H1-1 at the 1% level. Being an engineer increases the time spent collaborating by approximately 1.79 percent.

The results show that having industry grants has a significant influence on the time spent collaborating with industry, increasing the average amount of time by 3.2 percent, though the effect is only significant at the 10% level. There is a slight negative effect for the interaction effect of engineers with industry grants of -0.48 percent, but this is not surprising given how strong the effect of both being an engineer and having industry grants are separately.

Affiliation with a University Research Center has a positive influence on researcher's involvement with industry, though less substantial than for being an engineer. Affiliation with a URC results in an increase of 0.43 percent in the time a researcher spends collaborating with industry.

US citizens are more likely than non-native US citizens to be involved with industry. Being a native U.S. increases the time spent with industry by about 0.48 percent. Females spend a little less time collaborating with industry than their male counterparts. Being female decreases the time spent collaborating with industry by 0.24 percent.

H1-2: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to be an interface or resource for industry, including providing information about research advancements, placing students with industry, and serving as a consultant to industry.

The second model examined the extent to which researchers act as a resource for industry. The dependent variable is measured on a scale from 0 to 10, with 0 corresponding to a researcher having no contact or involvement with industry. Increases on the industrial resource scale indicate an increasing intensity and diversity of the relationship with industry.

The results from this model confirmed hypothesis H1-2 at the 1% level. Engineers are indeed more likely to act as a resource for industry than scientists. On the 0 to 10 industrial resource scale, being an engineer results in a positive shift of 1.7 on the scale. For a simple count measure of resource activities, engineers are likely to participate in 0.69 more resource activities than scientists (regression results not shown).

The results for model 2 also indicate that researchers with tenure are more likely to act as a resource for industry. Having tenure results in a positive shift of 0.41 on the industrial resource scale. This is not unexpected, as researchers who have achieved tenure are the ones most likely to have developed a reputation and to be attractive to industry for knowledge and collaboration. In addition, tenured faculty may have greater liberty to invest their time in activities that are not rewarded in the tenure process (i.e., those activities that don't necessarily lead to publications and citations). However, model 2 is the only model of the four where that relationship was statistically significant and significance was only at the 10% level.

Affiliation with a University Research Center has a positive influence on the likelihood of being a resource for industry. Affiliation corresponds with a positive increase of 0.59 on the industrial resource scale.

Being a native US citizen resulted in a 0.404 shift on the industrial resource scale, indicating that native US citizens are more likely to be a resource for industry. Results from this model, like that of the first model, showed that females were less likely to be a resource for industry. Being female resulted in a negative shift of 0.205 on the industrial resource scale.

H1-3: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to actively collaborate with industrial personnel in technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry.

Model 3 looked at the extent to which researchers are actively COLLAB with industry. Like the industrial resource scale, the industrial engagement scale is from 0 to 10, with 0 indicating no engagement activities. Increases on the scale represent an increase in the intensity and diversity of engagement. Hypothesis H1-3 was confirmed at the 1% level by the results of the model. Compared with being a scientist, being an engineer results in a 0.74 positive increase on the industrial engagement scale.

Affiliation with a university research center results in a positive shift of 0.3 in the industrial engagement scale, showing that researchers who are affiliated with URCs are more likely to be COLLAB with industry.

In this model, having government grants was statistically significant at the 5% level. Having public funding resulted in a positive shift of 0.171 on the industrial engagement scale.

Being female and being a native US citizen were both statistically significant at the 10% level. Being a US citizen resulted in a positive shift on the industrial engagement of 0.152. Tenure, the Number of Years since the PhD was awarded, being married and having children were not statistically significant.

H1-4: Compared with academic researchers who specialize in science, academic researchers who specialize in engineering will be more likely to believe that research funding decisions should emphasize the application of the research for the benefit of society over the researcher's own intellectual curiosity.

The fourth model examined the extent to which a researcher felt that funding decisions should emphasize the application of research for societal benefit. Engineers were significantly more likely to believe that funding decisions should consider application, confirming hypothesis H1-4 at the 1% level. Being an engineer increases the likelihood of believing that funding decisions should consider applications by 0.92. Specifically, the marginal effects for each category (not shown) indicated that being an engineer decreased the likelihood of being in the "Strongly Disagree" category by -0.14, decreased the likelihood of being in the "Disagree" category by -0.07, increased the likelihood of being in the "Agree" category by 0.15, and increased the likelihood of being in the "Strongly Agree" by 0.06.

Discussion and Conclusions

The purpose of this paper was to examine the differences between scientists and engineers with respect to their involvement with industry. The results of the four models showed that engineers and scientists have different behaviors and values with respect to their involvement with industry. PhDs in engineering are more likely to work in industry, to spend time working with industry, to be an interface for industry with academia, and to actively working with industry. In addition, engineers are more likely to believe that the application of research to society should be considered in funding decisions. Though the analysis does not evaluate the quality of the industrial involvement that academic researchers undertake, it does indicate differences in the diversity and intensity of the activities. Thus, there is substantial evidence that engineers are, in general, more oriented towards industry in their activities and attitudes than scientists are.

Notwithstanding the differences between scientists and engineers shown in the results, it is important to point out that the majority of academic researchers have no involvement with industry whatsoever. Though engineers are more likely to undertake activities involving industry and to spend time working with industry, the majority still spend no time with industry.

The distinction between engineers and scientists may seem to be self-evident and the importance trivial. However, the implications are often unexplored. Engineers are not merely applied scientists, just as technology is not simply applied science (Feibleman, 1961; Ziman, 1984). Though there are no universally accepted definitions, science is often simplistically thought of as the pursuit of knowledge for its own sake, and technology as the application of this fundamental knowledge (Ziman, 1984). However, this categorization belies the complex relationship between science and technology (Feibleman, 1961; Ziman, 1984). The innovation process is not a linear process where science precedes technology, which in turn feeds into commercial applications (Wise, 1985). Science and technology exist together in a complex, mutually dependent relationship (Barnes, 1982; Rip, 1992; Staudenmaier, 1992), but they are independent and distinct. Technology developed over millennium without the benefit of pre-existing scientific knowledge about why it worked (Feibleman, 1961; Price, 1965). Technological advancements have spurred scientific research and discovery, while scientific discovery has impelled and supported advancements in technology (Rip, 1992). Scientists and engineers come out of these different traditions.

Science is dominated by scientists, while technology is dominated by engineers (Landau and Rosenberg, 1986). Innovation is the product of both science and technology (Kline and Rosenberg, 1986). In the knowledge economy, where collaboration and networks of researchers are needed to develop knowledge and solve problems, scientists and engineers must work together to advance both science and technology.

Effective technology transfer and collaboration with industry requires academic researchers to overcome the organizational and disciplinary barriers that would prevent effective collaboration. Engineers are an important bridge between academia and industry. Their orientation to the application of research and towards greater involvement with industry, as shown in this paper, makes them a natural fulcrum in the innovation process. As pressure for more rapid development and deployment of scientific discovery to commercial applications increases, it may be possible to leverage the culture and conventions of engineers to affect this policy goal.

Chapter 3: The Effect of Departmental Research Resources

Introduction

Research universities are commonly touted as drivers of economic growth and technological innovation (Yusuf, 2007; Lendel, 2008; Lendel, Allen, and Feldman, 2009; Dill and van Vught, 2010). Thus, there has been increasing desire by policymakers, managers, and scholars to understand the role of research, technology transfer, and scientific collaboration in the economy. Scholars have sought to determine what organizational structures and individual characteristics make academic researchers most productive.

One of the short-comings of previous research on the university-industry linkages and science and technology policies has been the separation of individual and institutional factors. Studies of research outcomes aggregated to the institution-level make the implicit assumption that every department in a university has a homogeneous set of resources and, thus, an equal likelihood of producing a given outcome.

Conversely, studies at the individual-level often exclude institutional-level or work-group factors. Treating institutions as homogeneous with homogeneous goals, aspirations, and resources, is misleading. The quality and prestige of universities varies substantially, as do departments within universities (Clark, 1983). The prestige of research at a university is founded on academic disciplines and is heavily tied to individual departments and programs (Brewer, Gates, et al., 2002). University departments form the core of the work organization for most academics (Bechtel, 1986; van Knippenberg and Ellemers, 2003).

Organizational structure and culture influence the productivity of researchers (Hagstrom, 1965; Creswell, 1986; Blau, 1994 [1973]; Gulbrandsen and Smeby, 2005; Ponomariov, 2008) by establishing the standards for work, providing the resources needed to be successful, and promoting an attractive scholarly environment for high performing researchers. Researchers who join highly productive departments have been shown to rise to a similar level of academic productivity, regardless of their previous record (Long and McGinnis, 1981). Thus, the organization influences individual behavior and values (Pelz and Andrews, 1966; Long and McGinnis, 1981; Blau, 1994 [1973]; Gulbrandsen and Smeby, 2005). At the same time, the quality and productivity of individuals within a faculty has a large influence on the culture and academic reputation of the institution (Blau, 1994 [1973]; Nord and Fox, 1996). Productive and prestigious faculty can support or improve the reputation of a department and the institution it resides in (Wispé, 1963). The rankings of departments are highly correlated with the number of faculty publications and citations (Hagstrom, 1971; Drew and Karpf, 1981). There are also large and statistically significant correlations between departmental prestige and research opportunities, faculty size and quality (Hagstrom, 1971). Large, well-funded and well-managed research groups publish more, are more often cited, and enjoy higher peer recognition than do less well-funded, smaller research groups (Johnston, 1994). The prestige, quality, and effectiveness of a department are correlated with the academic productivity of the department (Allison and Long, 1990), largely because faculty publications, citations, and the production of new researchers are used by peers to evaluate academic success.

The organizational context is an important factor in the work behavior of individuals. A researcher's home department will often determine the quality of the colleagues and the resources that a researcher has access to, as well as the research standards and conventions that a researcher is expected to adhere to. Currently, universities and colleges in the United States are structured around departments, which are, in turn, constructed around academic disciplines. Departments have a significant influence over faculty behavior through the incentives and rewards that exist there, such as faculty recruitment, promotion, tenure, teaching assignments, and student enrollment (Lattuca, 2001). Departments also define the scope of validity of research within an academic field.

Most studies consider the effects of institutional-level factors on aggregated individual behavior. Ponomariov (2008), for instance, examined the effects of four institutional-level factors: (1) total citations; (2) total patents; (3) total Industrial R&D funding; and (4) total R&D funding on individual researchers and found that R&D funding for the institution had no statistically significant effect on the propensity of researchers to be involved with industry. Little research has been done at the departmental or field level, primarily because of the difficulty of getting data. In 1977, Harriet Zuckerman noted that there was relatively little known about the effect of particular universities or laboratories on human capital development (Zuckerman, 1977). An understanding of the influence of particular university departments or laboratories on individual behavior remains elusive. The purpose of this essay is to contribute to this understanding by exploring the relationship between departmental research resources and researcher involvement with industry.

Departmental Research Resources

Academic researchers are influenced by their membership in an academic discipline, their home department, and their institution (Hagstrom, 1965; Ellemers, Haslam, Platow, and van Knippenberg, 2003). However, it is unclear whether identification with an academic department or a researcher's academic discipline has greater influence on an individual's research behaviors and values. Departmental influences may be stronger than academic disciplines in many cases. For example, a researcher in a highly ranked department at an Ivy League institution, such as Harvard or Princeton, may experience very different expectations and pressures about publishing and obtaining external funding than a researcher in the same field in a less prestigious department.

The department that a researcher belongs to, and the accompanying academic expectations, culture, and research resources that are available there, are important in determining individual researcher performance (Creswell, 1986; Allison and Long, 1990). Allison and Long (1990) found that researchers who moved into more prestigious departments increased their level of productivity to correspond to the departmental conventions. This is due, in part, to the social and physical capital – the resources – that exist within those departments. Results of the study by Allison and Long found that the facilities and physical resources available at an institution affected the number of publications, while the intellectual stimulation from colleagues – the human resources within the institution – affected the quality of those publications.

Achieving success in any strategy or policy is not simply a matter of providing some goals or objectives. If this were the case, no policy would ever fail. Success or failure depends substantively in how policies are implemented (Pressman and Wildavsky, 1973). This, in turn, is dependent on how the resources needed for a policy are allocated and leveraged (Montjoy and O'Toole, 1979). Though organizational strategies frequently lead to the allocation of resources to achieve these objectives, so the availability, utilization, and allocation of resources have a significant impact on the direction and capabilities of an organization (Bower, Doz, and Gilbert, 2005). Resource dependence theory suggests that organizations respond to the external market and environmental demands because they need external resources in order to succeed (Pfeffer and Salancik, 2003 [1978]). In a knowledge economy, however, many of the resources needed for successful innovation and knowledge creation come from within the organization itself.

Resources can be classified in many ways. For the purposes of this paper, departmental research resources are divided into three categories: (1) human resources; (2) financial resources; and (3) physical resources. These three distinct types of resources have consistently been shown to be strongly associated with academic research productivity (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, and Leslie, 1992), academic rankings (Jones, Lindzey, and Coggeshall, 1982, pp. 15-29; Goldberger, Maher, and Flattau, 1995;

Ostriker, Kuh, and Voytuk, 2010, pp. 39-45), and institutional prestige (Volkwein and Sweitzer, 2006). For more details, please see Appendix B.

Human resources are the colleagues that academics have access to within their department. The importance of other academic researchers cannot be overemphasized. Researchers depend on the intellectual stimulation and feedback that colleagues provide to improve the content and quality of their research (Allison and Long, 1990). The professional networks that researchers work in provide the scientific and technical human capital that support collaborative research, knowledge creation, and academic productivity (Bozeman, Dietz, and Gaughan, 2001; Bozeman and Corley, 2004).

Several studies have shown that larger research departments (measured by the size of the faculty and student enrollment) are more prestigious, academically productive, are cited more often, and have better quality students (Hagstrom, 1971; Meadows, 1974; Long, 1978; Jordan, Meador, and Walters, 1988, 1989; Blau, 1994 [1973]; Kyvik, 1995; Dundar and Lewis, 1998). This has led researchers to postulate that faculty size itself is the main underlying factor producing these results (King and Wolfle, 1987). One study by King and Wolfle of latent variables of faculty reputational rankings (King and Wolfle, 1987) supports the focus on faculty size as a latent variable. King and Wolfle found that the size of the department was an important indicator of the departmental reputation, as measured in the 1982 NRC study (Jones, Lindzey, et al., 1982). Johnston (1994) found that single researchers in large departments were not sufficient to create well-respected faculty in a subfield. Rather, there needed to be a critical mass of at least four to six researchers, along with supporting graduate student researchers, working together in a specific specialization to be competitive in building an international reputation for the department. Larger departments are more likely to have several faculty members with similar research interests (Kyvik, 1995). They are also more likely to attract higher quality researchers (Dundar and Lewis, 1998), both because researchers may be attracted to current faculty members, but also because larger departments are more likely to have the resources needed to support eminent scholars. However, it is not simply the existence of a large number of people in proximity that creates productive researchers. Rather, it is the academic culture and intellectual stimulation that this group of people creates. The quality of the academic research measured through faculty publications and citations is highly correlated with the rankings of departments (Hagstrom, 1971; Drew and Karpf, 1981) and is an important component of the quality of the human resources in a department.

Financial resources in the forms of grants, contracts, and donations have long been considered essential for promoting quality research. Empirical studies have investigated the effects of financial resources and grants on faculty employment (Katz, 1980), researcher productivity (Katz, 1980), the number of PhD degrees awarded (Ellyson and Krueger, 1980; McCoy, Krakower, and Makowski, 1982), interactions with industry (Bozeman and Gaughan, 2007), research funding from nonfederal sources (Ellyson and Krueger, 1980; McCoy, Krakower, et al., 1982), and size of the faculty (McCoy, Krakower, et al., 1982; Mathies II, 2010). Research studies have found that there is a strong relationship between federal R&D funding and faculty size and quality. Katz (1980) found that federal R&D funding had a significant impact on both the employment and productivity of university professors, with the top 20 universities having larger faculties and getting substantially greater per faculty funding than other research universities. McCoy and her colleagues (1982) and Ellyson and Krueger (1980) both found that higher rates of federal R&D expenditures are accompanied by higher R&D funding from other sources, as well as greater numbers of faculty members and graduate students.

Well-funded faculty tend to be more productive, publishing more and having their works cited more often (Johnston, 1994; Adams and Griliches, 1998).[15] One study found that for every $1 million increase in federal research funding, there was an increase of 10 articles and 0.2 patents (Payne and Siow, 2003). Non-federal grants can also have a significant influence on researcher behavior and productivity. Researchers with grants from industry are substantially more likely to be involved with industry and to spend time working with industry (Gulbrandsen and Smeby, 2005; Bozeman and Gaughan, 2007; Ponomariov, 2008). Thus, financial resources within a department are expected to have an influence on the research activities of academic scientists and engineers.

Physical resources are the facilities, equipment, computer hardware, library holdings available to the researcher (Cartter, 1966; Hagstrom, 1971; Clark, Hartnett, and Baird, 1976). Physical resources allow researchers to complete empirical research, access and find previous research through publications, and have a stimulating environment to work in. In addition to access to human resources, access to equipment and facilities is one of the reasons that industry will seek academic

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[15] The direction of causality between funding and academic productivity is not unambiguous. External funding supports and promotes academic productivity, while productive and prestigious faculty has an advantage in competing for funding.

partnerships (Powers, Powers, Betz, and Aslanian, 1988; Zieminski and Warda, 1999). Thus, physical resources are another essential research resource.

While a minimum threshold of resources are necessary for research, particularly in experiment-based scientific and engineering fields (Stolte-Heiskanen, 1979; Allison and Long, 1990), the influence of departmental research resources on the behavior of individual researchers is not well understood. Resources are necessary for any individual to successfully complete their work. If resources are not available internally, individuals and organizations must seek them externally (Pfeffer and Salancik, 2003 [1978]). Alternatively, when internal resources are abundant, pressures to secure these resources externally may be reduced. Departments with significant research resources have the potential to be of greater use to industrial partners (Peters and Fusfeld, 1983; Powers, Powers, et al., 1988). On the other hand, greater internal resources may mean that researchers are not beholden to their relationship with industry to acquire resources and can focus on curiosity-driven research instead. Therefore, in departments with greater research resources, researchers may not feel the need to partner with industry or to seek these resources through affiliation with university research centers. Thus, the exact direction and magnitude of the relationship between resources and scientific productivity and performance is not clear (Stolte-Heiskanen, 1979; Kyvik, 1991; Gulbrandsen, 2000) and needs further research.

Hypotheses

Faculty members in research universities are required to conduct and publish research in order to get tenure, build their academic reputation and get promoted (Geisler and Rubenstein, 1989). In an environment where there is greater pressure to publish, there is expected to be a correspondingly greater pressure to collaborate since collaboration has been shown to increase academic productivity (Meadows, 1974; Bakanic, McPhail, et al., 1987). One study of collaboration found that researchers who worked alone or with only one collaborator published substantially fewer papers than those who worked with a large number of collaborators (Meadows, 1974). Papers with multiple authors (a common measure of collaboration), on the other hand, have a greater likelihood of getting accepted for publication (Bakanic, McPhail, et al., 1987).

As involvement with industry is generally a voluntary activity, a researcher must assess the time and effort required work with industrial partners and conclude that the involvement will have a net benefit for their research (Carayol, 2003; Perkmann, King, and Pavelin, 2011). Thus, researchers must either see that industrial involvement will provide resources or knowledge that cannot be acquired otherwise. Productive and eminent researchers are concerned with how activities will impact on their publications and academic productivity (Perkmann, King, et al., 2011). These researchers are generally located in higher-rated departments that value higher scholarly productivity (Crane, 1965; Allison and Long, 1990). Researchers in higher ranked departments will only work with industry if they see the value to their own career goals and research (Perkmann, King, et al., 2011). While this may include increasing publications, it can also include patenting and commercializing research.

Industrial partners are also conscious of the need to assess the benefits of any potential partnership with academia. Competition from the global marketplace make it increasingly difficult for private companies to recover research investments by establishing a long-term monopoly (Matkin, 1990). Since the 1980s, companies have looked to external sources in order to acquire new knowledge, processes, and products, rather than developing them internally (Rosenberg and Nelson, 1996; Chesbrough, 2003; Pallot and Pawar, 2006). University partnerships provide one source of new knowledge. In addition, university partnerships provide access to future human capital and new knowledge through the medium of students (Etzkowitz, 1999; Feller, 1999; Slaughter and Leslie, 1999).

At the same time, all levels of government are more conscious of the need to leverage university research to develop innovative products and services that will allow companies to compete globally, while increasing economic prosperity locally. The benefits of spillovers from knowledge networks are recognized by numerous stakeholders in the innovation process (Griliches, 1986; Jaffe, 1986; Jaffe, Trajtenberg, and Henderson, 1993; Rogers, 1995; Rosenbloom and Spencer, 1996). The federal government increasingly links funding to industrial partnerships and technology transfer (Rosenberg and Nelson, 1996). In 1994, Wesley Cohen and his colleagues (Cohen, Florida, and Goe, 1994a) estimated that 19 percent of university research involved industry linkages. It would hardly be surprising if this figure was higher today.

Faculty members in departments with greater research resources have access to better equipment, supplies, secretarial support, research assistants, travel funds, and teaching replacements (Dundar and Lewis, 1998). Faculty members at larger universities also generally have access to a greater number of capable colleagues in their own field (Blau, 1994 [1973]) or subfield (Dundar and Lewis, 1998) and, thus, more opportunity for collaboration. However, the perception of the adequacy of resources differs between departments and may not always match objective assessments (Stolte-Heiskanen, 1979). In a study of perceptions about resources and academic productivity, Stolte-Heiskanen (1979) found that researchers in departments with greater resources may actually perceive that there is a greater scarcity of resources than researchers in relatively smaller and poorer departments. Researchers in departments with greater federal funding have been found to collaborate more (Adams, Black, Clemmons, and Stephan, 2005). They are also more involved in patenting (Coupé, 2003; Geuna and Nesta, 2006; Breschi, Lissoni, and Montobbio, 2007; Carayol, 2007; Perkmann, King, et al., 2011) and in commercialization activities (Di Gregorio and Shane, 2003; O'Shea, Allen, Chevalier, and Roche, 2005). Increased involvement with industry does not seem to have detrimental effects on faculty either, since faculty members who publish prolifically in peer-reviewed journals are more likely to be involved in patenting and academic entrepreneurship (Perkmann, King, et al., 2011).

With more intense competition for resources (Etzkowitz, 1999) and greater ties in funding for industrial collaboration and involvement, it is expected that researchers in researchers in departments with greater research resources will actually undertake activities that will improve their access to more resources and academic productivity. Therefore, it is expected that the researchers in these departments will have greater involvement with industry, including the time spent working with industry, acting as a resource for industry, and actively collaborating with industry.

H2-1: Researchers in departments with greater departmental research resources will be more likely to spend time working with industrial personnel.

H2-2: Researchers in departments with greater departmental research resources will be more likely to be an interface or resource for industry, including providing information about research advancements, placing students with industry, and serving as a consultant to industry.

H2-3: Researchers in departments with greater departmental research resources will be more likely to actively collaborate with industrial personnel in technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry.

Variables and Methodology

To test the first hypothesis, H2-1, the dependent variable is the total percentage of time that a researcher spends working with industry [INDTIME]. The dependent variable for hypothesis H2-2 is the RESOURCE variable. The dependent variable represents the extent to which a researcher is active collaboration with industry [COLLAB]. These variables are discussed in detail in Chapter 1. The descriptive statistics for the explanatory and control variables is found in Table 3.1.

Table 3.1: Descriptive Statistics

Variable Description	Freq	Mean	Std Dev	Min	Max
Percentage of total research time spent working with industry [INDTIME]	1382	3.27	6.09	0	50
Researcher acts as a resource for industry [RESOURCE]	1384	2.69	3.35	0	10
Researcher is active collaboration with industry [COLLAB]	1384	1.37	2.44	0	10
Scientist [SCIENTIST]	772	0.56	0.49	0	1
Engineer [ENGINEER]	612	0.44	0.49	0	1
Human Resources Factor [HUMAN]	1262	.01	0.88	-1.09	6.04
R&D Expenditures [R&DEXP]	1384	21.07	31.38	0	424.48
R&D Expenditures squared for curvilinear	1384	1427.83	5988.57	0	180185
Physical Resources Factor [PHYSICAL]	1384	0.02	0.49	-0.39	11.08
Number of Years since the PhD was awarded [YEARSWITHPHD]	1372	19.12	11.22	2	57
Tenure [TENURE]	964	0.70	0.46	0	1
Married [MARRIED]	1153	0.86	0.35	0	1
Number of children living at home [CHILDREN]	644	0.86	1.12	0	10
US Citizen [USCITIZEN]	981	0.71	0.45	0	1
Affiliated with a University Research Center [CENTAFF]	566	0.41	0.49	0	1
Female [FEMALE]	691	0.49	0.50	0	1
Government Grants [GOVGRANT]	658	0.475	0.499	0	1
Industry Grants [INDGRANT]	107	0.077	0.267	0	1
Engineer with industry Grant [ENGINDGRANT]	75	0.05	0.23	0	1

Explanatory and Control Variables

To test the influence of the departmental research resources on individual researchers, three research resource variables will used in the models. Appendix B contains a full description of the background and methodology used to obtain these variables: one for human resources [HUMAN], one for financial resources [R&DEXP], and one for physical resources [PHYSICAL]. Previous research has shown that R&D expenditures likely have a curvilinear influence, with a peak effect and diminishing returns (Clark, 2009). The curvilinear nature of the relationship is controlled for by included the square of the R&D variable in the model [R&DEXP2].

As results from Chapter 2 show, academic differences influence the behavior of scientists and engineers working in universities. The results showed that engineers were more likely to be both a resource for industry and to be active collaboration with industry. Thus, whether the researcher is an engineer were included in the model [ENGINEER].

Control variables for number of years since the PhD was awarded [PHDYEARS], whether the researcher has been awarded tenure [TENURE], whether the individual is supported by government grants [GOVGRANTS], whether the individual is supported by industrial grants [GOVGRANTS], marital status [MARRIED], number of children [CHILDREN], whether the researcher is a native U.S. citizen [USCITIZEN], whether the researcher is female [FEMALE], whether the individual is affiliated with a University Research Center [CENTAFF], and an interaction variable for engineers with industry grants [ENGINDGRANT][16] will all be included in the model. These variables have all been shown in previous research using the RVM data to impact collaboration behavior and research values (Lee, 2004; Corley and Gaughan, 2005; Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Bozeman and Gaughan, 2007; Su, 2010). The models will also be weighted to account for the disproportionate sampling of women that was done in the research design (Research Value Mapping Program, 2005). A more complete discussion of the justification for the explanatory and control variables can be found in Chapter 2.

Results

Table 3.2 presents the results of the regression models. For the ZINB models used to test the hypotheses, the average marginal effects with unstandardized coefficients are presented. Overall, the empirical results show mixed support for the hypotheses. Human resources have a positive influence for the time spent collaborating (not statistically significant), whether a researcher acts as a resource for industry (statistically significant at the 5% level), and whether a researcher actively engages with industry (statistically significant at the 1% level). Financial research resources have an overall positive influence on the time spent collaborating with industry. The physical resources have a negative effect for each of the three models.

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[16] ENGINDGRANT is excluded from models 2 and 3 because industry grants are a component of the construct for the dependent variables.

Table 3.2 Marginal Effects for Regression

	INDTIME (zinb)	RESOURCE (zinb)	COLLAB (zinb)
Human Resources Factor [HUMAN]	0.306 [0.217]	0.393 ** [0.171]	0.299 *** [0.094]
R&D Expenditures [R&DEXP]	0.069 *** [0.024]	-0.003 [0.007]	-0.005 [0.115]
R&D Expenditures squared for curvilinear effect [R&DEXP2]	-0.0005 ** [0.000]	0.0000 [0.000]	0.000 [0.000]
Physical Resources Factor [PHYSICAL]	-1.380 *** [0.453]	-0.526 ** [0.234]	-0.327 * [0.175]
Engineer [ENGINEER]	1.481 *** [0.414]	1.255 *** [0.262]	0.347 *** [0.098]
Number of Years since the PhD was awarded [YEARSWITHPHD]	-0.017 [0.027]	-0.017 [0.011]	0.002 [0.009]
Tenure [TENURE]	0.571 [0.408]	0.265 [0.187]	0.045 [0.057]
Has Government Grants [GOVGRANT]	-0.189 [0.142]	-0.079 [0.077]	0.093 * [0.049]
Has Industry Grants [INDGRANT]	4.651 * [2.701]		
Married [MARRIED]	0.092 [0.283]	0.001 [0.191]	0.018 [0.089]
Number of children living at home [CHILDREN]	-0.031 [0.083]	-0.0005 [0.040]	0.013 [0.014]
US Citizen [USCITIZEN]	0.784 ** [0.331]	0.450 ** [0.193]	0.137 ** [0.067]
Affiliated with a University Research Center [CENTAFF]	0.366 * [0.198]	0.553*** [0.178]	0.214 ** [0.086]
Female [FEMALE]	-0.369 *** [0.130]	-0.255 *** [0.074]	-0.060 ** [0.031]
Engineer with Industry Grant [ENGINDGRANT]	-0.644 *** [0.211]		
Observations	1220	1220	1220
McFadden's Adjusted R^2	0.052	0.074	0.068
Cragg-Uhler (Nagelkerke) R^2	0.657	0.789	0.683
Robust Standard Errors in Brackets * significant at 10%; ** significant at 5%; *** significant at 1%			

H2-1: Researchers in departments with greater departmental research resources will be more likely to spend time working with industrial personnel.

The first model evaluated the time spent collaborating with industry. The influence of the departmental research resources was mixed. The variable measuring the quality of the departmental colleagues did not have a statistically significant influence on the amount of time a researcher spends collaborating with industrial partners. Financial research resources and physical research resources, on the other hand, did have statistically significant influences. Every $1000 increase in financial research resources in the department led to a 0.069 percent increase in the amount of time a researcher collaborated with industry, with a slight negative effect of -0.001 percent of time from the curvilinear nature of the relationship. Physical research resources – indicated by capital expenditures on equipment, library volumes, and institutional endowment – had an overall negative effect of –1.38 percent for every 1 unit increase in the physical resource factor, indicating that the greater the physical resources available to the researcher, the less likely the researcher is to be involved in resource activities.

Being an engineer has a strong positive effect on the time spent collaborating with industry, with engineers spending an additional 1.48 percent of their time collaborating with industry. This confirms the results from the model in Chapter 2. Native US citizens spent an additional 0.78 percent of their time collaborating with industry. Women, on the other hand, were less likely to collaborate with industry, with being a female leading to an average reduction of -0.238 in the time spent collaborating with industry.

Having an industry grant increased the likelihood of a researcher spending time collaborating with industry. Industry grants increased the time spent collaborating by 3.23 percent (significant at the 10% level). Being an engineer with an industry grant had a small negative effect of -0.644 percent of a researcher's time. The negative interaction effect is small compared to the large effects of being an engineer and having an industry grant.

Affiliation with a university research center has a positive influence on the time a researcher spends collaborating with industry by 0.366 percent.

H2-2: Researchers in departments with greater departmental research resources will be more likely to be an interface or resource for industry, including providing information about research advancements, placing students with industry, and serving as a consultant to industry.

The results from the second model showed mixed support for hypothesis H2-2. The quality of the human resources within a department had a positive and statistically significant effect on the likelihood that a researcher will act as a resource for industry. A one unit increase in the human resource factor leads to an increase of 0.393 on the industrial resource scale. This indicates that the higher the quality of the faculty, – represented by the number of faculty members, the number of graduate students and PhD graduates, the average number of publications per faculty member and the average citations per publication, – the greater the likelihood that a researcher will act as a resource for industry.

The financial resources in a department did not have a statistically significant influence on the likelihood that a researcher will act as a resource for industry.

As with the model for the time spent collaborating with industry, the physical research resources in a department had a negative influence on the likelihood that a researcher acts as a resource for industry. A one unit increase in the physical resource factor leads to a -0.526 decrease on the industrial resource factor scale. This indicates that researchers in departments with relatively more physical research resources were less likely to be involved in resource activities, including consulting for industry, discussing their research with industry, or placing students with industry.

Confirming the results from Chapter 2, engineers are more likely to act as a resource for industry, with being an engineer increasing the diversity and intensity of the resource activities by 1.255 on the industrial resource scale.

Affiliation with a university research center has a positive influence on industrial engagement, as does being a native U.S. citizen, both leading to an increase by approximately 0.5 on the industrial resource scale. Being a female has a detrimental effect of -0.255 on the industrial resource.

H2-3: Researchers in departments with greater departmental research resources will be more likely to actively collaborate with industrial personnel in technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry.

The results of the model showed mixed support for the likelihood that a researcher was actively collaborate with industry. Human resources have a positive influence on whether a researcher is actively COLLAB with industry by 0.299 on the industrial engagement scale. Financial research resources had no statistically significant influence on industrial engagement, though whether a researcher has a government grant had a positive effect. This indicates that while the financial resources within a department are not a significant influence on industrial engagement, having direct financial support is.

Departmental physical research resources had a negative effect on industrial engagement, as it did for the models for the time spent collaborating with industry, and acting as a resource for industry. A one unit increase in the physical research resources led to a -0.327 decrease in industrial engagement scale. This effect was smaller than for the models for time spent collaborating with industry and being a resource for industry and had lower statistical significance. This indicates that, while the effect is still there, physical resources have a smaller influence on a researcher's decision to actively engage with industry. This may be the result of the fact that active engagement activities – working for a company, patenting or commercializing research, and co-authoring – often involve more downstream research application which may rely on the physical resources of the department and institution less.

The results confirmed that engineers are more likely to be collaborating with industry. Being an engineer led to a positive increase of 0.347 on the industrial engagement scale. This is consistent with the findings from the model in Chapter 2, though the effect has been decreased with the addition of departmental research resources. This may indicate that there is an interaction between the resources in a department and the culture created by the academic discipline. Being affiliated with a university research center, and being a native U.S. citizen still had positive effects on industrial engagement comparable to the models in Chapter 2. Affiliation with a URC led to an increase of 0.214 on the industrial engagement scale. Being a native U.S.

citizen led to an increase of 0.137 on the industrial engagement scale. Being female had a slightly negative effect on industrial engagement, as it has for the other models.

Discussion and Conclusions

Resources are an essential component for the success of any endeavor in an organization. Resources are the inputs into the production process (Grant, 1998) that allow the organization to produce desired outcomes, whether this is a physical product, service, or knowledge. In the academic environment, resources provide an essential component to knowledge creation and academic productivity.

The purpose of this paper was to examine the influence of departmental research resources on the collaborative behavior and technology transfer activities of academic researchers. Resources were classified as human, financial, and physical. The different types of resources had different effects on researchers.

Human resources had a significant positive influence on the activities that researchers undertook with industry. Researchers in larger departments with academic colleagues, who published more often and were cited more, were more likely to act as a resource for industry and to be active collaboration with industry. Interestingly, departmental human resources did not have a statistically significant influence on the time that a researcher spent working with industry, however. This indicates that academic colleagues do not influence the amount of time that a researcher spends working, though they do influence the types of activities that a researcher undertakes. The results show that the quality of a researcher's departmental colleagues influences a researcher's collaborative behavior and technology transfer activities.

The influence of financial resources on researchers was mixed. Researchers in departments with greater R&D funding spent slightly more time working with industry. Those with direct funding from industry, meanwhile, were substantially more likely to spend time working with industry than those without industry grants. This result shows that industry funding is an important incentive to getting researchers to collaborate with industry. This is hardly surprising, however, since industry funding is typically tied to more applied, short-term research rather than curiosity-driven research (Klevorick, Levin, et al., 1995). At the same time, government grants had a slight negative influence on the likelihood that a researcher would spend time working with industry or act as a resource for industry. However, neither of these effects was statistically significant. Conversely, government grants had a positive and statistically significant effect on the likelihood that a researcher was active collaboration with industry. This may be the result of the encouragement (and often requirement) of industrial partnerships for federal funding. This finding supports the previous research that has shown connections between federal R&D funding and the propensity of researchers to be involved in technology transfer activities (Coupé, 2003; Di Gregorio and Shane, 2003; O'Shea, Allen, et al., 2005; Geuna and Nesta, 2006; Breschi, Lissoni, et al., 2007; Carayol, 2007; Perkmann, King, et al., 2011).

Perhaps one of the most interesting and unexpected findings was the negative influence that physical research resources had on industrial involvement activities. This may be because the researchers in relatively wealthier departments do not need to be involved with industry in order to gain access to the physical resources that they need to do their research.

One of the central components of any public policy is the allocation of public resources. Universities have been forced to deal with scarce resources (Etzkowitz, 1999) and researchers face more competition for R&D funding (Dill, 1996; Newman, Courturier, and Scurry, 2004; Yusuf, 2007). Considering the desire of policy makers to promote industrial involvement and technology transfer, the mixed results of the models are somewhat hard to interpret. One conclusion is that the effect of different resources on researchers is complex. The incessant striving for bigger facilities and larger endowments may not actually promote better technology transfer, though it may indeed promote greater academic productivity and better teaching, neither of which is measured here. On the other hand, larger faculties and more productive colleagues actually encourage involvement in technology transfer activities and the physical resources may be necessary to attract these higher quality faculty members. Research universities are faced with a complex array of activities and goals. The trinity mission of teaching, research, and service can create substantial tensions for an institution. The allocation of resources to support one of these missions may actually undermine another.

One of the challenges of any comparative study is ensuring the consistency of any measure used. Perceptions about the adequacy of resources may differ significantly among researchers (Stolte-Heiskanen, 1979). Thus, objective measures, such as dollars spent on R&D expenditures or equipment may fail to capture the influences that the perceptions of quality of differences in resource levels may have on researchers.

The degree that faculty members are involved with industry and technology transfer activities is one way to gauge the relative importance of the activity to the department and to the institution (Matkin, 1990). These results are limited to an analysis of the effect of research resources available within the department. Equally important can be the culture created in the department by the managerial emphasis on different types of activities and the reward and incentive structure established. Thus, it is possible that an unobservable quality or managerial influence would help to explain the behavior of researchers more fully.

The results also indicate that single construct measures of quality or prestige are unlikely to be adequate in capturing the dynamics of the relationship of different types of resources. Department rankings and prestige measures are typically based on the resources available within those departments – the number of faculty members, number of graduate students, R&D expenditures, and so forth. While there is a strong correlation between these rankings and academic productivity (Volkwein and Sweitzer, 2006), there needs to be a deeper understanding of the influence of specific types of resources on researchers.

Department-level reward systems are grounded in academic disciplines and do not necessarily encourage industrial involvement (Matkin, 1990). This may conflict with the overall goals of the institution and policy-makers to increase strong university-industry connections. The success or failure of technology transfer activities is dependent of the congruence between the activities and the prevailing academic culture (Matkin, 1990). Institutions that create entrepreneurial environments, such as MIT and Stanford, are likely going to have greater success in promoting industrial involvement than institutions that do not have this same organizational culture. For other institutions, however, the allocation of resources can send strong signals about the priorities and strategy of the institution (Stolte-Heiskanen, 1979; Barney, 1991; Segal-Horn, 1998; Barney and Clark, 2007). In light of the findings of this paper, further exploration of the role of departmental research resources is warranted.

Chapter 4: University Research Centers and Academic Disciplines

Introduction

Interdisciplinary research is considered essential for understanding and solving the complex scientific and social problems of today (Birnbaum, 1982). Thus, politicians, policymakers, and research managers have encouraged interdisciplinary collaborative research, based on the belief that it makes research more innovative and creative. R&D programs, institutional structures, and funding incentives all now emphasize and encourage interdisciplinary research. New types of university research centers were developed in the 1980s to encourage and foster multi-disciplinary collaboration (Blum, Fossum, and Lardner, 1986; Geiger, 1990; Bozeman and Boardman, 2003). Unfortunately, simply bringing people into the same space will not necessarily result in collaboration (Salter and Hearn, 1996c; Melin, 2000) or increased productivity. Academic socialization and resources play powerful roles in determining research conventions, behaviors, and outcomes (Becher, 1989; Huber and Shaw, 1992; Clark, 1995). These can prove significant barriers to interdisciplinary research.

Despite the apparent benefits of interdisciplinary research, researchers often face daunting obstacles and disincentives in crossing disciplinary boundaries, including: communication or “culture” barriers; organizational barriers; and funding barriers (Committee on Facilitating Interdisciplinary Research, 2004). This leads to the question about why some researchers cross disciplinary boundaries and what perceived benefits they derive from this effort.

The primary research question addressed in this essay is whether scientists who choose to affiliate with a URC dominated by engineers will exhibit greater involvement with industry, similar to engineers, than scientists in general. In other words, does working and working with a group dominated by researchers with different disciplinary conventions and values significantly influence the behavior of those scientists?

This chapter will focus on the 641 researchers responding to the RVM survey who are affiliated with URCs. The models will consider the influence on individual behavior and attitudes of the disciplinary population of the URC that a researcher is affiliated with.

Interdisciplinary Research

Collaboration should not be confused with interdisciplinary research, though both are promoted by policymakers and university administrators as essential to research and effective problem-solving. Interdisciplinary research does not necessarily require collaboration, nor is collaboration necessarily interdisciplinary. Collaborators may be from a small homogeneous group and have the same disciplinary background and conventions. On the other hand, interdisciplinary research can be the outcome of an individual researcher pulling (or borrowing) knowledge, methodologies, or theories from other fields (Salter and Hearn, 1996c). Research scientists have been socialized into a particular method of scientific investigation and problem-solving. Each discipline has specific standards and conventions for research, observation, deduction, and the formulation of research problems. In addition, each discipline has particular areas of concern and theoretical paradigms, which influence how phenomenon are understood (Bruhn, 2000). Interdisciplinary research requires questioning and expanding these disciplinary standards in order to consider alternative paradigms and interpretations.

Interdisciplinary research can be seen as both a challenge and threat to traditional disciplines. Typically, it is the function of a discipline to provide its researchers with its own problems and its own processes for studying these problems. Researchers are socialized into their academic discipline in the process of completing their education (Becker and Carper, 1956; Turner, Miller, et al., 2002). This socialization process establishes the rules, rights, and rites that individuals must adhere to if they are to be members of a particular academic group (Beaver and Rosen, 1978). It also defines what sets the group apart from other groups. Thus, an academic discipline is both a unit of social organization and mediator between individual scientists and other social units (Bechtel, 1986) and it has a powerful influence on establishing the conventions and standards for academic researchers. Interdisciplinary research is risky, particularly for faculty members still aspiring to be recognized and accepted within their home department (i.e., to get tenure and be promoted to full professor), because it is outside the disciplinary boundaries drawn for research in most university departments in the United States (Bruhn, 2000). Thus, universities, academic departments, and individual researchers struggle with where and how interdisciplinary research fits into the rigid structure of traditional scholarship (Bruhn, 2000). In addition, disciplinary conventions and standards can be significant barriers to a researcher looking to engage in interdisciplinary research (Kahn and Prager, 1994; Klein, 1994; Benowitz, 1995;

Salter and Hearn, 1996a). Interdisciplinary research necessarily requires crossing disciplinary boundaries (Cummings and Kiesler, 2005) and moving outside of the safety of one’s own discipline.

Potential interdisciplinary collaborators must confront a variety of challenges that are not encountered when research remains within an academic discipline. Different academic disciplines have different training and cultures, use different vocabularies and research methods, even to describe the same phenomenon, and have different research conventions (Clark, 1995; Maglaughlin, 2003). Thus, potential collaborators must find common ground upon which to build their research (Caudill and Roberts, 1951). In addition, academic publications are usually firmly grounded in one academic discipline and finding an audience for interdisciplinary research can be difficult (Kahn and Prager, 1994), particularly when the research goes against common disciplinary conventions. Researchers often find that promotion and tenure, which are controlled by the academic department the researcher belongs to, are tied to the perception of making scholarly contributions to the field of knowledge within their home discipline. Thus, interdisciplinary research is often promoted by institutions and policymakers without a firm understanding of the disciplinary and structural impediments to its success (Salter and Hearn, 1996c). New institutional structures, such as University Research Centers, have been created to try to foster interdisciplinary and multidisciplinary collaboration (Cohen, Florida, et al., 1994b; Gray, Lindblad, and Rudolph, 2001; Bozeman and Boardman, 2003; Boardman and Corley, 2008), in the hopes of leveraging the perceived benefits of increased innovative research.

Despite the emphasis on the need and importance of interdisciplinary research, previous research has generally focused on communication, disciplinary barriers, and the nature of the work itself (see for example, Caudill and Roberts, 1951; Luszki, 1958; Gaff and Wilson, 1971; Birnbaum, 1978, 1979b; Birnbaum, 1979a; Birnbaum, 1981b, 1982; Saxberg, Newell, and Mar, 1982; Kraut, Galegher, and Egido, 1987; Klein, 1990, 1994, 1996a, 1996b; Salter and Hearn, 1996b; Lattuca, 2001; Palmer, 2001; Maglaughlin, 2003; Cummings and Kiesler, 2005). On the other hand, research on University Research Centers as an alternative organizational structure, aimed at fostering interdisciplinary research, has focused more on the creation, operation, and influence of these institutions on researchers (Bozeman and Boardman, 2003; Bozeman and Corley, 2004; Boardman, 2006; Bozeman and Gaughan, 2007; Shrum, Genuth, et al., 2007; Boardman and Corley, 2008; Sá, 2008), with little explicit consideration of the nature and intensity of the interdisciplinary nature of collaborations. The interdisciplinary nature of the research in URCs is often assumed based on the stated mission and organizational structure of the centers.

A few notable exceptions have explicitly considered the influence of the organizational structure of URCs on interdisciplinary collaboration and research. In his doctoral dissertation, Sang-Jin Lee (Lee, 1999) looked at interdisciplinary research in 142 engineering and material science research centers and institutes. Lee surveyed research directors and found that they reported high levels of interdisciplinary research. Barry Bozeman and some of his colleagues have considered the influence of affiliation with URCs on the collaborative behavior of academic researchers in different disciplines. In several of these studies (Boardman, 2006; Boardman and Corley, 2008;

Bozeman, 2009; Bozeman and Boardman, 2010), the authors accounted for the extent of the interdisciplinarity of the URCs in their models. All of these studies used the number of disciplines or departments represented within the URC to measure the degree of interdisciplinarity of the collaboration and research. However, this fails to measure the intensity of the interdisciplinary nature of the research. Collaboration can still be considered interdisciplinary if, for example, a research team has 10 electrical engineers but only one physicist on it. Simply reporting that two disciplines were involved would be misleading though, since it implies there is an equal distribution of the disciplinary influences.

University Research Centers

Higher Education institutions have a long history of working with industry and in focusing on the application of research to solve problems of industry and agriculture (Rosenberg and Nelson, 1996). The 1862 Morrill Land Grant Act provided start-up funds for colleges and university to states through large tracts of lands that could be sold. These grants explicitly emphasized the foundation and support of education in agriculture, engineering and home economics (Grayson, 1993). However, technology transfer activities that detract from the traditional mission and activities of universities or that conflict with the prevailing academic conventions and public expectations are likely to get relegated to organizations tangential to academic departments, such as university research centers (Matkin, 1990).

University Research Centers (URCs) became commonplace in the 1980s and 1990s as an alternative research unit outside of the departmental structure of research universities. Though URCs existed much earlier, the adoption of the institutional structure grew in response to calls for increased innovation and transfer of university knowledge to industry in order to support economic growth (Geiger, 1990; Guston, 2000), and to the perceived limitations of discipline-based research, typically done in academic departments, to understanding and solving complex technical and social problems (Ziman, 1994; Lee, 1999; Boardman and Corley, 2008). Thus, URCs were, in many ways, a response to the external needs and pressures on universities to support activities and research that the traditional department-structure could not accommodate.

In 1965, there were approximately 3,500 centers on university campuses (Palmer and Druzas, 1965). By 1982, the number of centers had grown to 5,422 (Thomas and Ruffner, 1982). By 2006, there were an estimated 14,353 research centers (Wood, 2006). Correspondingly, URCs have been the focus of much research of university-industry collaboration, scientists' productivity, and innovation. This paper aims to contribute to the understanding of the role that URCs play in supporting interdisciplinary research. Specifically, the influence of URC affiliation and academic discipline on research activity and industrial involvement were tested.

Though the growth of URCs may partially reflect the substantial growth in higher education institutions overall during this period, it is also reflective of institutional choices about the appropriate organizational structures for research. Previous research has shown that there are many benefits to URC affiliation, including: increased researcher involvement with industry (Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Bozeman and Boardman, 2010); improved opportunities for research (Corley and Gaughan, 2005) and collaboration (Boardman and Corley, 2008; Clark, 2009; Ponomariov and Boardman, 2010); increased support for graduate students (Corley and Gaughan, 2005; Bozeman and Boardman, 2010); and improved access to resources (Boardman, 2006). At the same time, affiliation with a Research Center can create tension and challenges for a researcher who must balance the requirements and standards of both the home department and the URC (Boardman and Bozeman, 2007). There continue to be significant institutional and disciplinary barriers, as well as professional risks, to interdisciplinary research (Bauer, 1990; Turner, Miller, et al., 2002; Corley, Boardman, and Bozeman, 2006), particularly outside the traditional departmental structure.

Table 4.1: URC affiliation by Discipline

	Total	Affiliated with URC	Percent affiliated with URC (%)	Average size of URC
Scientists	772	300	38.9	52.9
Life	292	106	36.3	64.0
Physical	480	194	40.4	46.8
Engineers	612	266	43.5	40.3
Mathematicians and Computer Scientists	249	75	30.1	35.1
Total	1636	641	39.3	45.5

In the RVM survey of academic researchers, 641 of the 1636 researchers (39.3 percent) identified an affiliation with 550 unique University Research Centers. Table 4.1 shows URC affiliation by discipline. Researchers from different academic disciplines have different propensities to be affiliated with URCs. Engineers are the most likely to be affiliated with a URC, with approximately 43.5 percent of all engineers having some URC affiliation. Approximately 38.9 percent, or 300 scientists, acknowledged that they were involved with a URC, with physical scientists being more likely to be involved in a center than life scientists. Mathematicians and computer scientists were the least likely to be involved in a URC, with only 30.1 percent identifying some affiliation.

There is also significant variation in the size of URCs. Some have just a handful of people.[17] Other centers have hundreds, or even thousands,[18] of affiliated faculty members. There is a difference in the size of the URCs that different academic disciplines are involved in. Overall, scientists are typically affiliated with the largest URCs. The average size of the affiliated URC for scientists in the RVM survey is 52.9 people. Life scientists are generally in the largest URCs, with an average of 64.0 people. Physical scientists are in smaller URCs generally, with an average of 46.8 people. For engineers, affiliated URCs have an average of 40.4 people. Mathematicians and computer scientists tend to be affiliated with the smallest URCs, with an average of 35.1 people.

Hypotheses

Individual behavior is influenced by the groups and organizations that one claims membership in. Social identity theory postulates that people will classify themselves into various social categories, such as work organizations (Tajfel and Turner, 1985; Ashforth and Mael, 1989) and professions (Bar-Tal, 1998). Group membership provides an identity for individuals (Abrams, 1996). It also establishes conventions of behavior in order to maintain group membership (Bar-Tal, 1998). In addition, group membership can enhance an individual’s social capital through affiliation with the

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[17] For the RVM survey, respondents were asked to only consider URCs that had at least 5 members.

[18] While URCs of this size are relatively rare, they are not uncommon in biomedical and medical fields.

group's social network and resources (Bordieu, 1986; Lin, 2001). Organizational culture can also play an important role in providing the rules and standards for work and behavior of members (Hebb, 1954, 1955; Schein, 1996a). Since affiliation with a URC is generally voluntary (Boardman and Bozeman, 2007), faculty members are choosing to belong to a particular URC and to acquire membership in a particular work group.

Getting researchers to cross disciplinary boundaries is more complicated than simply bringing potential collaborators together. Disciplinary socialization and training may form powerful, and unconscious, traditions and conventions, furnishing taboos, boundaries, social structures, hidden assumptions, and acceptable patterns of communication (Becher, 1989; Huber and Shaw, 1992). Potential collaborators must establish a common foundation for proceeding with research, including explicitly defining the research problem, establishing the theoretical concepts and methods that were used, and agreeing on the handling and interpreting of data (Caudill and Roberts, 1951). University research centers have actually been criticized for failing to promote interdisciplinary collaboration (Stahler and Tash, 1994). Disciplinary conventions and standards for research may make collaboration with researchers with significantly different conventions and methodologies more difficult. Thus, researchers may prefer to work and collaborate with researchers with more similar disciplinary conventions. Therefore, it is expected that all researchers are more likely to be affiliated with centers that are dominated by the discipline to which they themselves belong.

H3-1: Researchers are more likely to be affiliated with university research centers that are dominated by their own academic disciplines.

Social identity theory predicts that identifying oneself with a particular group influences the behavior of individual members as they strive to conform to group conventions, values, and expectations (Siegel and Siegel, 1957; Ellemers, Haslam, et al., 2003). In academic research, colleagues are an important social influence because they influence the decisions about which problems to pursue, which the methodologies to use, where to publish results, and whether the results are acceptable to the scholarly community that a researcher is a part of (Hagstrom, 1965). As shown in Chapter 3, the quality of one's colleagues can also influence involvement with industry and technology transfer activities.

However, social identity is complex and dynamic. An individual may identify with numerous groups at the same time or with select parts of a group or institution (Ellemers, Haslam, et al., 2003). The influence that a particular group's conventions and standards exert on an individual's behavior is dependent on how strongly an individual identifies with the group and wishes to maintain membership (van Knippenberg and Ellemers, 2003). Thus, the disciplinary perspectives and structures engrained through socialization and training may eclipse or limit the institutions and organizations designed to promote interdisciplinary exchange and synthesis (Palmer, 2001). On the other hand, the desire to be accepted by one group, or to establish and maintain group membership, may influence individuals to exhibit behavior and values that conflict with those of other groups to which they belong.

University Research Centers are external to the traditional departmental structure of research universities (Cohen, Florida, et al., 1994b; Cohen, Florida, et al., 1996; Bozeman and Boardman, 2004). They were developed to provide alternative incentive structures and resources to academic researchers in the hopes of encouraging interdisciplinary research, innovation, and technology transfer (Geiger, 1990; Guston, 2000).

As discussed above, the majority of researchers affiliated with a URC do so in a center dominated by their own academic discipline. Only 35.3 percent of scientists were affiliated with URCs dominated by another academic discipline. Of these about half (17.3 percent overall) were affiliated with URCs dominated by engineers. In voluntarily joining a URC dominated by engineers, a scientist is necessarily expressing a desire to be a part of an organization that is dominated by a different academic discipline. Since URCs were originally created as an avenue to increase interdisciplinary collaboration, applied research, and technology transfer, the question naturally becomes whether affiliation with a URC dominated by another discipline will result in behaviors corresponding to those of the dominant group?

In Chapter 2, the results established that engineers are more likely to be involved with industry in all three of the measures used: time spent working, industrial resource activities, and industrial collaboration. Previous research has established that affiliation with a URC has a positive influence on industrial involvement. Researchers in URCs are more likely to be involved with industry (Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Bozeman and Boardman, 2010). URCs provide improved opportunities for collaboration (Boardman and Corley, 2008; Clark, 2009; Ponomariov and Boardman, 2010), increased support for graduate students (Corley and Gaughan, 2005; Bozeman and Boardman, 2010), and improved access to resources (Boardman, 2006). Thus, there is reason to believe that the benefits of being in a URC itself are independent of the disciplinary group that dominates the center.

Nevertheless, scientists who are willing to work in URC dominated by engineers necessarily accept that their research will involve interaction with researchers with different conventions, values, and methodologies. Furthermore, it is expected that the opportunity to interact with these alternative conventions and paradigms is actually desirable, since scientists are voluntarily collaborating in the affiliation.

The programs and projects undertaken by a University Research Center are often shaped by the needs and interests of the funding entity, rather than the academic research interests of the researcher (Stahler and Tash, 1994). Affiliation with a URC necessitates accepting the mission of the URC, and, to a certain extent, the conventions and standards of the group members. Thus, for URCs dominated by engineers, it is likely that the conventions and the standards of that URC will reflect the conventions and standards of engineers with greater collaboration with industry and industrial involvement. It is expected that scientists voluntarily working in these URCs will exhibit behavior and values that reflect these standards and conventions.

H3-2: : Scientists who are affiliated with university research centers that are dominated by engineers are more likely to spend more time working with industrial personnel than scientists who are affiliated with university research centers dominated by scientists.

H3-3: Scientists who are affiliated with university research centers that are dominated by engineers are more likely to be an interface or resource for industry, including providing information about research advancements, placing students with industry, and serving as a consultant to industry than scientists who are affiliated with university research centers dominated by scientists.

H3-4: Scientists who are affiliated with university research centers that are dominated by engineers are more likely to actively collaborate with industrial personnel in *technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry than scientists who are affiliated with university research centers dominated by scientists.*

Variables and Methodology

To test the first hypothesis, H3-1, a bivariate response variable measuring whether any URC that a researcher that is affiliated is dominated by their own academic discipline (i.e., has a majority of researchers who are from the same discipline) [URCOWN]. This variable was obtained by determining the number of researchers in each URC by academic discipline category: life scientist, physical scientist, engineer, or mathematician and computer scientists. The percentage for each category was calculated (summing to 100%). Finally, the dominant disciplinary category was determined. The dependent variable was created by matching the dominant disciplinary category with the discipline of the individual researcher to determine if these were the same.[19] The resulting variable is bivariate response variable. The most appropriate model for discrete bivariate variables is a multinomial logit or probit, depending on whether the errors are assumed normal (probit) or logistic since the linear regression model produces inefficient parameter estimates and biased standard errors (Long, 1997). Though both types of models were run, only the results from the logit model were presented.

The dependent variable for Hypothesis H3-2 is the time spent working with industry [INDTIME], discussed in greater detail in Chapter 1. The variable is a measure of the percentage of time that a researcher spends working with industry. The variable

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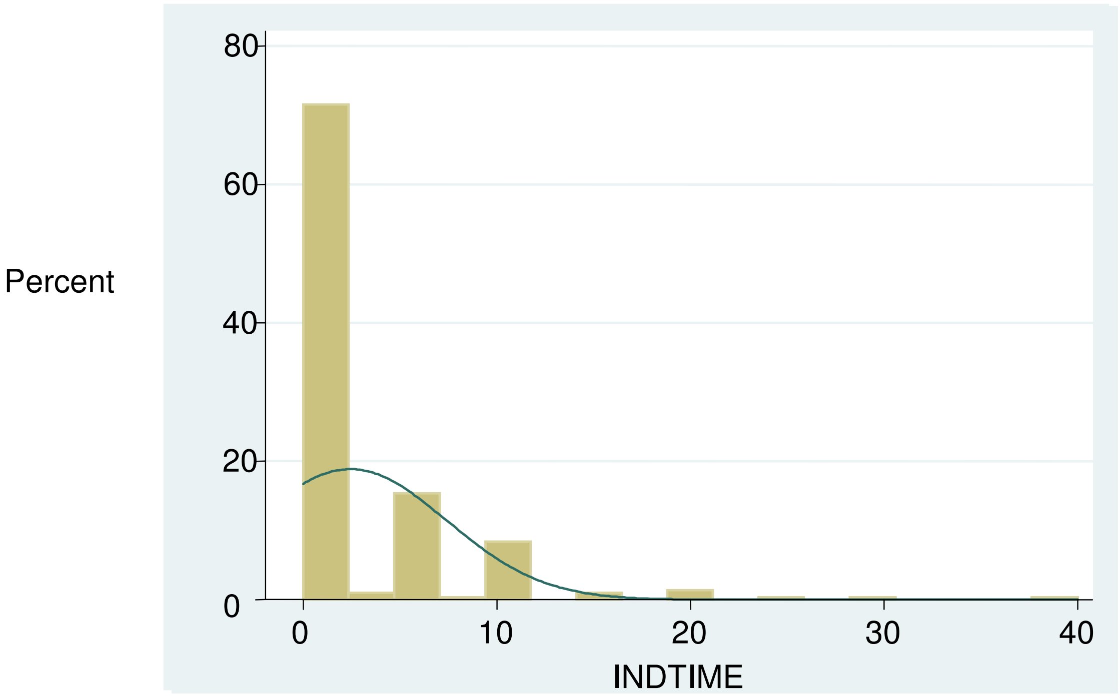
[19] For purposes of this model, scientists were explicitly classified as either life scientists or physical scientists.

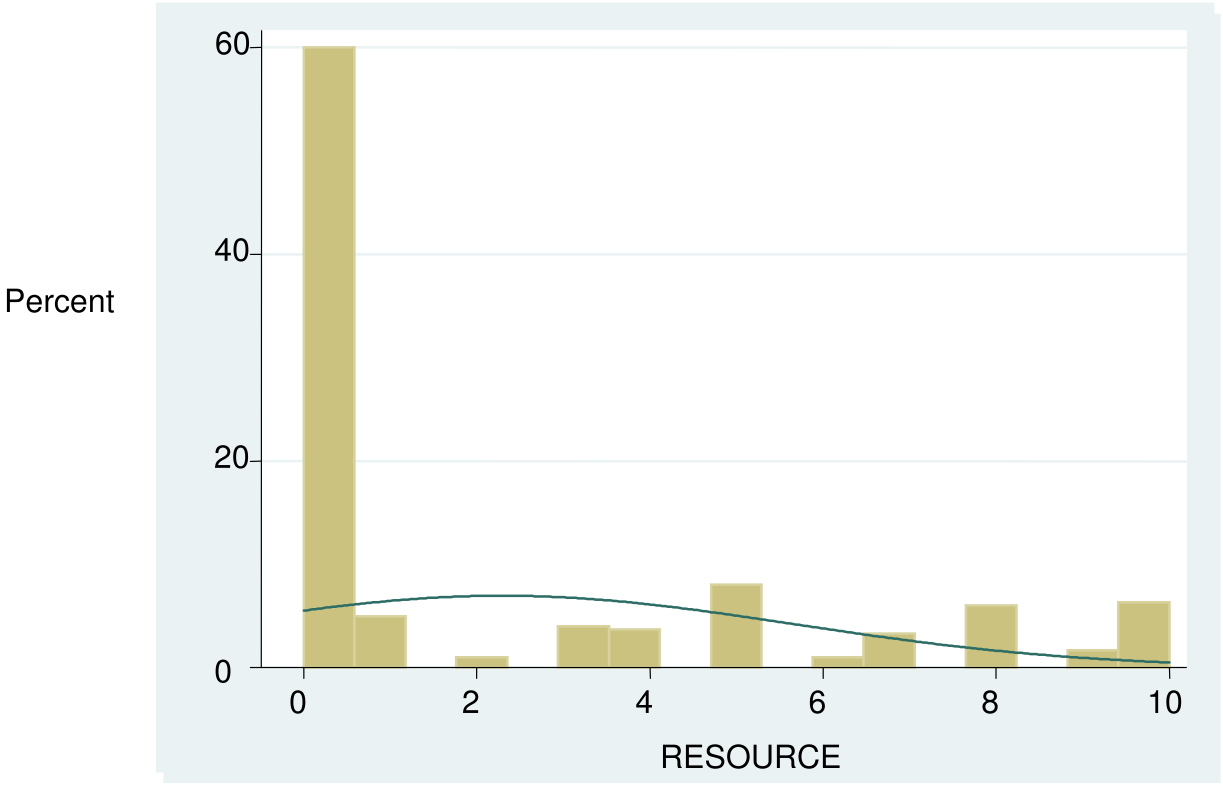
is bounded by 0 and 100, which makes an OLS regression model estimate both biased and inefficient because the variable is censored. The variable is also heavily weighted with zeros, even when using the subgroup of those affiliated with URCs (please see Figure 4.1). In order to account for the excesses of zeros, a Zero Inflated Negative Binomial model is used.

Figure 4.1: Distribution of INDTIME variable for Researchers Affiliated with URC



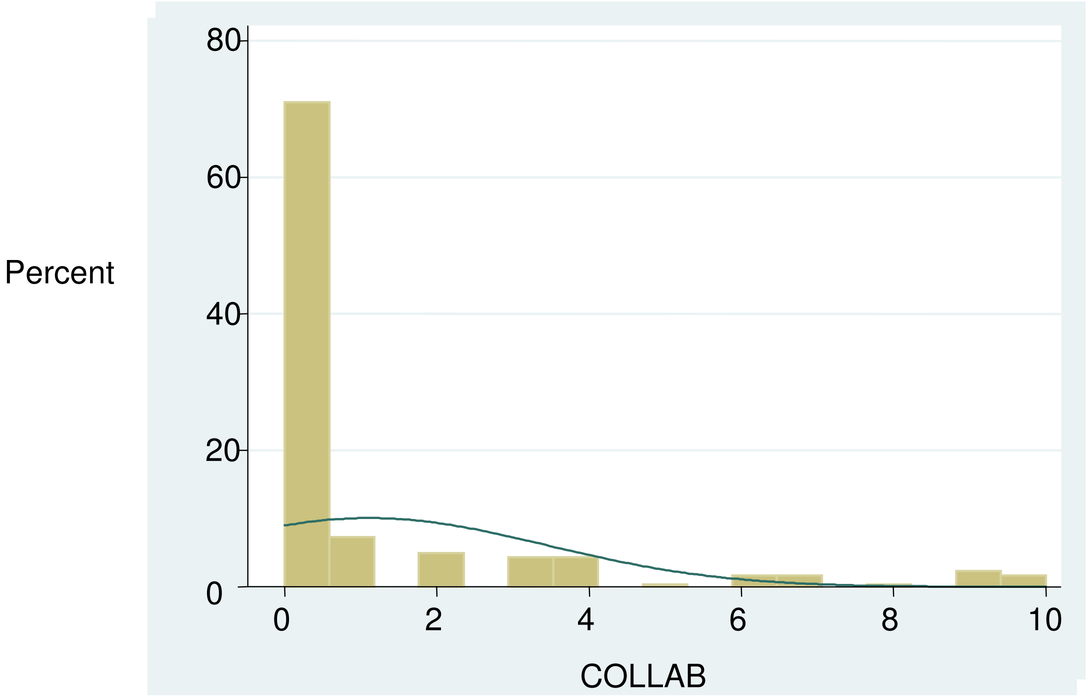
To test the hypothesis H3-3, the dependent variable is RESOURCE, which measures whether a researcher has been involved with activities in which one acts as a resource for industry in the previous 12 months. The variable is still heavily weighted with zero responses, even for the population of researchers working in University Research Centers (please see Figure 4.2). In situations where there is a substantial number of zero responses with a count or ordinal variable, as occurs with this variable, a Zero Modified Count Model is more appropriate than a regular Poisson or Negative Binomial model since it assumes that the population is actually divided into two groups: individuals who are not involved with the activity and those would given the right opportunity, but who have not done so within the previous 12 months. A Zero Modified Count Model allows for the explicitly modeling of the zero responses (Long, 1997). A Zero Inflated Poisson model was used.

Figure 4.2: Distribution of RESOURCE for Researchers Affiliated with URC



To test the hypothesis H3-4, the dependent variable is COLLAB, which measures whether a researcher has active collaboration with industry in the previous 12 months by. As discussed in Chapter 1, Poisson or Negative Binomial Regression models are normally used for ordinal or count variables. In this case, a Zero Modified Count Model is more appropriate since it allows for the explicitly modeling of the excessive zero responses (Long, 1997), still evident despite the limitation to researchers affiliated with URCs (please see Figure 4.3). Therefore, a Zero Inflated Negative Binomial model was used.

Figure 4.3: Distribution of COLLAB for Researchers Affiliated with URC



Explanatory and Control Variables

For the first model used to test H3-1, only the 641 respondents that are affiliated with a University Research Center were included in the model. Academic dummy variables for life scientists, physical scientists, engineers, and mathematicians were used to account for academic disciplines in the model. Descriptive statistics for the data used for the model testing H3-1 are found in Table 4.2.

Table 4.2: Descriptive Statistics for H3-1

Variable Description	Freq	Mean	Std Dev	Min	Max
Affiliated with University Research Center dominated by own discipline [OWN_URC]	644	0.677	0.468	0	1
Scientist [SCIENTIST]	300	0.466	0.499	0	1
Life Scientists [LIFE]	106	0.165	0.371	0	1
Physical Scientist [PHYSICAL]	194	0.301	0.459	0	1
Engineer [ENGINEER]	266	0.413	0.493	0	1
Mathematicians and Computer Scientists [MATH_CS]	640	0.116	0.321	0	1
Number of Years since the PhD was awarded [YEARSWITHPHD]	640	18.695	10.836	2	57
Tenure [TENURE]	458	0.711	0.454	0	1
Industry Grants [INDGRANT]	68	0.106	0.308	0	1
Government Grants [GOVGRANT]	324	0.503	0.500	0	1
Married [MARRIED]	555	0.870	0.337	0	1
Number of children living at home [CHILDREN]	305	0.855	1.068	0	8
US Citizen [USCITIZEN]	469	0.728	0.445	0	1
Female [FEMALE]	351	0.545	0.498	0	1

The following were controlled for in the models: the number of years since the PhD was awarded [PHDYEARS], whether the researcher has been awarded tenure [TENURE], whether the individual is supported by government grants [GOVGRANTS], marital status [MARRIED], number of children [CHILDREN], whether the researcher is a native U.S. citizen [USCITIZEN], whether the researcher is female [FEMALE], and whether the individual is affiliated with a University Research Center [CENTAFF]. Previous research has shown that these variables impact collaborative behavior, involvement with industry, and research values (Lee, 2004; Corley and Gaughan, 2005; Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Bozeman and Gaughan, 2007; Su, 2010). In addition, the model were weighted to account for the disproportionate sampling of women in the survey (Research Value Mapping Program, 2005). Please see Chapter 2 for a more complete discussion of the justification for the explanatory and control variables.

For the remaining three models testing H3-2, H3-3, and H3-4, the data are limited to the scientists that have acknowledged an affiliation with a URC, which reduces the number of observations to 300. Descriptive statistics for this data are found in Table 4.3.

Table 4.3: Descriptive Statistics for H3-2, H3-3, and H3-4

Variable Description	Freq	Mean	Std Dev	Min	Max
Percentage of total research time spent working with industry [INDTIME]	299	2.437	4.977	0	40
Researcher acts as a resource for industry [RESOURCE]	300	2.293	3.366	0	10
Researcher is active collaboration with industry [COLLAB]	300	1.113	2.325	0	10
Scientist [SCIENTIST]	300	1	0	1	1
Life Scientists [LIFE]	106	0.353	0.479	0	1
Physical Scientist [PHYSICAL]	194	0.647	0.479	0	1
Number of Years since the PhD was awarded [YEARSWITHPHD]	300	20.287	10.936	3	57
Tenure [TENURE]	215	0.717	0.451	0	1
Industry Grants [INDGRANT]	16	0.053	0.225	0	1
Government Grants [GOVGRANT]	144	0.480	0.500	0	1
Married [MARRIED]	258	0.866	0.341	0	1
Number of children living at home [CHILDREN]	126	0.743	1.004	0	1
US Citizen [USCITIZEN]	228	0.76	0.428	0	1
Female [FEMALE]	162	0.54	0.499	0	1

Results

H3-1: Researchers are more likely to be affiliated with university research centers that are dominated by their own academic disciplines.

Table 4.4 presents the statistics for URC populations by disciplinary affiliation. The average disciplinary affiliation of all faculty members affiliated with a URCs is presented in the columns, while the respondents' disciplines are presented in rows. For scientists, the average population of the URC they were affiliated with was 75.2 percent scientists, 16 percent engineers, and 1.6 percent mathematicians and life scientists. Life scientists and engineers were affiliated with URCs with the highest percentage of faculty members from their own discipline. Life scientists were affiliated with URCs that had populations of 73.6 percent life scientists, 10.3 percent physical scientists, 4.3 percent engineers, and 1.3 percent mathematicians and computer scientists. On average, 5.4 percent of the faculty members in URCs that life scientists were affiliated with was medical personnel. Engineers were affiliated with URCs that had populations of 67 percent engineers, 8.9 percent life scientists, 13.8 percent physical scientists, and 1.7 percent mathematicians and computer scientists. Physical scientists and computer scientists were generally in URCs that were more multidisciplinary. The URCs that physical scientists were affiliated with had populations of 53.4 percent physical scientists, 17.1 percent life scientists, 22.4 percent engineers, and 1.7 percent mathematicians and computer scientists. Mathematicians and computer scientists were in URCs where mathematicians and computer scientists still had the largest disciplinary representation at 47.2 percent, but they were no longer the majority in the URC.

Table 4.4: URC populations

Population of URC	Scientists	Life	Physical	Engineers	Math CS	Med	Other
For scientists	75.2%	37.1%	33.1%	16.0%	1.6%	3.7%	3.4%
For life scientists	83.9%	73.6%	10.3%	4.3%	1.3%	5.4%	5.1%
For physical scientists	70.5%	17.1%	53.4%	22.4%	1.7%	2.8%	2.5%
For engineers	22.7%	8.9%	13.8%	67.0%	2.7%	3.1%	4.4%
For math/CS	16.1%	10.9%	5.4%	19.9%	47.2%	2.8%	13.9%

Table 4.5 presents the URC populations by the mode of dominant disciplines of the URC. In each discipline, most faculty members were affiliated by centers that were single discipline centers. That is, it was most typical for faculty members to be in centers where 100 percent of affiliated faculty members came from a single discipline.

Table 4.5: URC population mode

Population of URC	Scientists	Life	Physical	Engineers	Math CS	Med	Other
Mode of URC for scientists	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mode of URC for life scientists	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mode of URC for physical scientists	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Mode of URC for engineers	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mode of URC for math/CS	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%

Table 4.6 presents the statistics for disciplinary affiliation by the dominant academic discipline in the URC and the percentage of those in URCs dominated by engineers. Physical scientists were more likely than life scientists to be affiliated with URCs dominated by engineers. Less than 2 percent of life scientists were affiliated with centers dominated by engineers, while about one quarter of physical scientists was. Mathematicians and computer scientists were also substantially more likely than life scientists to be in URCs dominated by engineers, with 18.7 of all mathematicians and computer scientists choosing to be affiliated with engineer-dominated URCs.

Table 4.6: URC affiliation by dominant academic discipline of URC

	Affiliated with URC	In URC dominated by own discipline	Percent in URC dominated by own (%)	In URC dominated by engineers	Percent in URC dominated by engineers (%)
Scientists	300	194	64.7	52	17.3
Life	106	88	83.0	2	1.9
Physical	194	106	54.6	50	25.8
Engineers	266	204	76.7	204	76.7
Mathematicians and Computer Scientists	75	37	49.3	14	18.7
Total	644	435	67.9	270	42.1

For the 641 researchers affiliated with a URC, 67.9 percent are in a URC dominated by their own discipline. Life scientists are the least likely to be involved in URCs dominated by other disciplines. Eighty three (83.0) percent of life scientists are affiliated with centers dominated by life scientists, while only 1.9 percent of life scientists work in URCs dominated by engineers. Similarly, 76.7 percent of engineers are affiliated with URCs dominated by engineers. Mathematicians and computer scientists are the most likely to be in URCs dominated by other academic disciplines, with slightly more than half having affiliation with such a URC.

The regression model evaluated the odds that a researcher was affiliated with a URC dominated by his or her own academic discipline. The results of the logit regression for the model used to test H3-1 are presented in Table 4.7.

Logit results are presented as changes in Odds. That is the regression result should be interpreted as the variable leading to a change in odds of collaborating in the activity. The results show strong support for the hypothesis that researchers are more likely to be involved in URCs that are dominated by their own discipline.

Supporting the statistics in Tables 4.4, 4.5, and 4.6, life scientists and engineers have the greatest odds of working in a URC dominated by their own discipline. Being a life scientist increases the odds that a researcher works in a URC dominated by life scientists by 6.285. Being an engineer increases the odds by 6.423. Physical scientists, mathematicians and computer scientists are less likely to be in URCs dominated by their own discipline, though the preference for a URC with one's own discipline is still very strong. Being a physical scientist increases the odds of being in this type of center by 4.779. For mathematicians and computer scientists, the odds are increased by 4.927.

Interestingly, having a government grant decreases the likelihood of a researcher being affiliated with a URC dominated by the same academic discipline. This may be indicative of the ties of government funding to interdisciplinary research which encourage multi-disciplinary research.

Table 4.7: Regression Results for H3-1

Affiliated with University Research Center dominated by Own Discipline	OWN_URC (logit)
Life Scientists [LIFE]	6.285 [1.443] ***
Physical Scientists [PHYSCI]	4.779 [1.444] ***
Engineer [ENGINEER]	6.423 [1.456] ***
Mathematicians and Computer Scientists [MATHCS]	4.927 [1.478]***
Number of Years since the PhD was awarded [YEARSWITHPHD]	-0.002 [0.013]
Tenure [TENURE]	-0.109 [0.416]
Industry Grants [INDGRANT]	-0.141 [0.423]
Government Grants [GOVGRANT]	-0.566 [0.329] *
Married [MARRIED]	-0.595 [0.661]
Number of children living at home [CHILDREN]	-0.059 [0.119]
US Citizen [USCITIZEN]	-0.564 [0.346]
Female [FEMALE]	0.214 [0.293]
Constant	-3.352 [1.633]
Observations	634
McFadden's Adjusted R^2	0.089
Cragg-Uhler (Nagelkerke) R^2	0.198
Robust Standard Errors in Brackets * significant at 10%; ** significant at 5%; *** significant at 1%	

Results for the models testing H3-2, H3-3, and H3-4 are presented in Table 4-8.

Table 4.8: Marginal Effects for Regressions for H3-2, H3-3, H3-4

	INDTIME (zinb)	RESOURCE (zinb)	COLLAB (zinb)
Affiliated with a University Research Center that is dominated by Engineers [URC_ENG]	0.303 [0.327]	1.400 [0.868]	1.221 ** [0.485]
Number of Years since the PhD was awarded [YEARSWITHPHD]	-0.048 [0.066]	-0.034 [0.028]	0.008 [0.026]
Tenure [TENURE]	0.937 [0.797]	1.187 [0.761]	-0.168 [0.282]
Industry Grants [INDGRANT]	1.032 ** [0.482]		
Government Grants [GOVGRANT]	-0.113 [0.209]	0.557 [0.533]	0.281 [0.325]
Married [MARRIED]	-0.253 [0.720]	-0.521 [0.730]	0.039 [1.246]
Number of children living at home [CHILDREN]	0.064 [0.119]	-0.130 [0.203]	0.012 [0.135]
US Citizen [USCITIZEN]	0.387 [0.369]	-0.067 [0.506]	-0.209 [0.216]
Female [FEMALE]	-0.205 [0.286]	-0.184 [0.429]	0.290 [0.796]
Observations	297	298	298
McFadden's Adjusted R^2	0.052	0.018	0.050
Cragg-Uhler (Nagelkerke) R^2	0.656	0.359	0.574
Robust Standard Errors in Brackets *significant at 10%; ** significant at 5%; *** significant at 1%			

H3-2: Scientists who are affiliated with university research centers that are dominated by engineers were more likely to spend more time working with industrial personnel than scientists who are affiliated with university research centers dominated by scientists.

The results do not support the hypothesis. The only statistically significant factor for the time spent working with industry for scientists affiliated with University Research Centers is having an industry grant, which increases the amount of time a researcher spends with industry by 1.03 percent. Being affiliated with a URC dominated by engineers does have a positive influence, but it is not statistically significant and cannot be differentiated from the null hypothesis of no effect.

H3-3: Scientists who are affiliated with university research centers that are dominated by engineers were more likely to be an interface or resource for industry, providing information about research advancements, placing students with industry, and serving as a consultant to industry than scientists who are affiliated with university research centers dominated by scientists.

The model examined the extent to which researchers act as a resource for industry. The results of the model looking at whether affiliation with a URC dominated by engineers has a positive influence on scientists does not support the hypothesis, though the results are only marginally above the 10% statistically significance threshold. The results indicate that there is a positive influence of 1.399 on the industrial resource scale. No other variable in the model is statistically significant either.

H3-4: Scientists who are affiliated with university research centers that are dominated by engineers were more likely to actively collaborate with industrial personnel in technology transfers activities, including patenting, commercializing research, co-authoring with industry, and working directly for industry than scientists who are affiliated with university research centers dominated by scientists.

The fourth model looked at the extent to which being affiliated with a URC dominated by engineers had a positive influence on the industrial collaboration of scientists. The results of the model show that being affiliated with a URC dominated by engineers does have a positive and statistically significant influence on scientists. Being affiliated with an engineer-dominated center results in an increase of 1.22 on the industrial collaboration scale, indicating that scientists are more involved in the collaboration activities of co-authoring, patenting, commercializing research, and working directly for a private sector company.

Discussion and Conclusions

Overall, the models show some interesting results about the likelihood of researchers collaborating in interdisciplinary research and the effects of such activity. Researchers are substantially more likely to be affiliated with a URC dominated by their own academic discipline. Assessing the interdisciplinary nature of University Research Centers considered the number of discrete disciplines in a URC (see for instance, Boardman, 2006; Corley, Boardman, et al., 2006), not the percentages of each discipline. So, for instance, a URC with representation from physics, electrical engineering, and mathematics was counted as being an interdisciplinary URC. In addition, each field in life science, physical science, and engineering was counted as a separate academic discipline. This classification does not necessarily show the depth of academic differences. However, accounting for the percentages of each type of academic discipline can yield a much fuller measure and reveal different influences. Thus, a URC with twenty physicists, one electrical engineer, and one mathematician, has a significantly different degree of interdisciplinarity than a URC with ten physicists, ten electrical engineers, and ten mathematicians, even though by discipline count, these centers are identical.

One of the fundamental reasons for the creation of the unique organizational structure of University Research Centers outside of the traditional departmental structure (Boardman and Corley, 2008) was to encourage interdisciplinary research (Cohen, Florida, et al., 1994b; Cohen, Florida, et al., 1996; Bozeman and Boardman, 2004). However, there have been questions and criticisms about the effectiveness of such structure to create truly interdisciplinary relationships and collaboration (Klein, 1994, 1996a, 1996b). The results of the first model would seem to support this concern. Looking at the percentages of researchers from different academic disciplines indicates that most researchers do not, in fact, cross disciplinary boundaries, even when working with researchers in a URC.

Interdisciplinary research requires crossing disciplinary boundaries and learning new languages and methodologies (Stahler and Tash, 1994). This may not be as comfortable or natural for a researcher as staying within one's own disciplinary area. In addition, rewards and academic advancement are dominated by the home department of a researcher, which determines promotion eligibility largely by success within one's own discipline (Lattuca, 2001; Maglaughlin, 2003; Cummings and Kiesler, 2005). Thus, the departmental and disciplinary attachments may overshadow the influence of the URC structure (Lattuca, 2001). It is also possible that researchers who work with researchers within their own disciplinary field may feel that there is greater appreciation and support from their home departments than those who engage in URCs dominated by other fields.

There is some evidence that a center does not necessarily ensure increased interdisciplinary activity (Geiger, 1990). Few scientists have been trained on how to effectively collaborate with colleagues from other disciplines or to use technology to collaborate across distances (Birnbaum, 1978; Salter and Hearn, 1996b). Thus, scientists who choose to collaborate in a URCs dominated by engineers must make an effort to understand the culture, standards, methods, and vocabulary of engineers.

Notwithstanding making those efforts, there is no conclusive evidence about the effects of such interaction and affiliation on scientists. There is support for the hypothesis that working with a group dominated by engineers does lead to greater industrial collaboration for scientists. However, there is no support that it influences the amount of time spent working with industry and only suggestive support that it influences whether a researcher acts as a resource for industry. These results must be taken as tentative, but they suggest that scientists who choose to work with engineers exhibit some increase in industrial involvement, though it is impossible with the results of this study to attribute this influence directly to working with engineers. It is equally likely that researchers that self-select to work with engineers have a predisposition to industrial involvement or are in an academic discipline that displays characteristics similar to engineers. In the case of this study, most of the scientists who are affiliated with URCs dominated by engineers are actually physical scientists. Only 2 of the 52 scientists affiliated with engineer-dominated centers are not physical scientists. Therefore, it is possible that further studies that distinguishing between life and physical scientists may find that there is as much (or more) differences between these academic groups as there is between scientists and engineers. Physical scientists may feel more comfortable with the application of their research or with being involved with engineers or industry than life scientists do. Since so few life scientists choose to be affiliated with a URC dominated by engineers, there may be further disciplinary effects at play that cannot be fully explored with this dataset.

The possible implications of the lack of substantial interdisciplinary research, even within the alternative organizational structure of University Research Centers, warrant further investigation. Results of previous research do indicate that URCs are effective mechanisms for increasing industrial involvement and technology transfer

(Maglaughlin, 2003). They have also been shown to improve opportunities to collaboration (Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Bozeman and Boardman, 2010). Whether they are effective mechanisms for interdisciplinary research, however, is yet to be proven.

Chapter 5: Conclusions

The benefits of collaboration and interdisciplinary research are oft promoted (Salter and Hearn, 1996b). Interdisciplinary research brings together disparate points of views, expertise, and abilities to solve complex problems (Birnbaum, 1982). However, there are significant boundaries to this type of research arising out of institutional and disciplinary cultures. University faculties are generally clustered in single discipline departments and often have little contact with researchers from other disciplines (Drucker, 1985; Foster and Kaplan, 2001; Hesselbein, Goldsmith, and Somerville, 2002; Christensen, 2003 [1997]; Govindarajan and Trimble, 2010). Cross-sector and interdisciplinary research requires crossing disciplinary boundaries and cultures (Ham and Mowery, 1998). Crossing these disciplinary boundaries, in turn, requires extra efforts by researchers (Caudill and Roberts, 1951; Luszki, 1958), which are not necessarily rewarded by home departments or professional associations within the discipline (Benowitz, 1995; Bruhn, 2000). Those researchers who choose to be involved with research activities that involve other disciplines or industrial partners are necessarily indicating a willingness to cross disciplinary boundaries and to sublimate their own independent research goals with those of their research partners.

Universities have endeavored to overcome the challenges of the traditional organizational structures and processes within the universities by employing new and expanded institutions and activities, including: the creation of centers and institutions; active promotion of research; patenting and licensing of inventions to industrial users;

and providing funding to university spin-off companies and start-up ventures. In the last thirty years, several different types of organizations and institutions have arisen outside of the traditional university structure, with the purpose of fostering effective collaboration between industry and university researchers and facilitating knowledge creation and technology transfer. The creation of science parks and bridging institutions has been widespread (Bercovitz and Feldman, 2003). University Research Centers (URCs) and Research Institutes have become meeting places for scientists and engineers from academia and industry. There is no template for creating, funding, or managing the centers (Bozeman and Boardman, 2003). These centers can have researchers from a single discipline or from multiple disciplines (Mowery and Sampat, 2001). However, affiliation with URCs has been shown to increase collaboration with industry (Geiger, 1990; Bozeman and Boardman, 2003), and thus, these alternative institutional forms have been shown to effectively increase technology transfer.

On the surface, these units would seem to be successfully changing the work of academic researchers. However, changing the conventions and culture of an organization or an individual is not always easy. Though one of the main goals of University Research Centers has been to promote interdisciplinary research (see for example, Geiger, 1990; Guston, 2000; Bozeman and Boardman, 2003; Corley and Gaughan, 2005; Boardman, 2006; Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007; Boardman and Corley, 2008; Clark, 2009; Bozeman and Boardman, 2010; Ponomariov and Boardman, 2010), the results of the models in Chapter 4 show that this goal is not necessarily being met. Though nearly 40 percent of academic researchers are affiliated with a URC, most choose to belong to URCs that are dominated by their own academic disciplines. While URCs may be providing an alternative institutional environment for collaboration and industrial involvement, they are not necessarily ensuring interdisciplinary research. This supports early research by Philip Birnbaum, who found that independent research institutions and URCs did not necessary lead to increases in interdisciplinary research (Birnbaum, 1978; 1979a; 1979b, 1981a, 1981b, 1981c), though they were effective organizational structures for increased integration (Birnbaum, 1982). Though these results should not be taken as definitive, or as indications that URCs are ineffective, they do indicate that encouraging interdisciplinary research is more difficult than simply promoting it or creating alternative institutional structures.

Interdisciplinary research is often promoted and encouraged for ideological reasons without an understanding of the difficulties and barriers that exist (Salter and Hearn, 1996c). If interdisciplinary research is indeed the goal, then the reward and incentive structure in academic (discipline-based) departments will need to reflect this. Interdisciplinary research will need to be appreciated more and graduate students integrated into the values and conventions of interdisciplinary research as they are being socialized into an academic discipline.

Organizations have often struggled with changing their missions and operations, sometimes unsuccessfully. While new capabilities, knowledge, and resources can be acquired, incorporating them into the existing organizational structure and processes can be very difficult (Cummings and Kiesler, 2005). They can make it difficult to absorb and use knowledge and technology that was not developed internally (Christensen, 2003 [1997]). Typically an organization’s structure has developed over time. Its processes were generally established to serve the achievement of the organization's goals. These structures and processes can, however, create impediments to successful innovation and change (Foster and Kaplan, 2001). These results also encourage further research exploring the depth and nature of interdisciplinarity at URCs and the effects on researchers of working in interdisciplinary centers.

Though there is an acknowledged difference in the work styles and attitudes of engineers and scientists, the full implication of these differences has been left unexplored by policymakers and university administrators. A greater understanding of the influences of academic training may facilitate the design of better incentives and organizational structures to accomplish institutional and policy goals. The results of the models in Chapter 2 show that engineers have a greater propensity for working with industry. The results of the models in Chapter 4 indicate that crossing disciplinary boundaries to work with engineers can lead to increased industrial involvement for the scientists who do it. However, the vast majority of the scientists who do work in engineer-dominated URCs are physical scientists. This may indicate that physical scientists are more likely to be involved with industry than life scientists. These strong disciplinary differences may indicate that the academic socialization process in different disciplines either encourages or discourages later collaboration with industry and interdisciplinary research (Branscomb, Kodama, and Florida, 1999). Thus, it is unlikely that significant increase in interdisciplinary research and industrial collaboration will occur without additional incentives and changes in the disciplinary conventions.

Departmental Research Resources

Resources are essential, though not sufficient, for the success of any organizational endeavor. However, there is an assumption that more resources are always better (Burris, 2004; Hevenstone, 2008; Lee, 2009). In his doctoral dissertation studying the effect of resources on federal agency performance, Soo-Young Lee (2009) found that the relative influence of resources can be difficult to discern. Some resources have a positive influence on organizational performance, while other types have negative or insignificant effects. The results of the models in Chapter 3 support Lee's findings and show that the relationship between departmental resources and individual performance is more complex than initially assumed. Different resources can have very different effects. Not all resources equally support the attainment of institutional goals. In fact, the influence of different resources may counteract, or even undermine, those of another.

For industrial involvement, human resources have a positive influence on the intensity and breath of activities, though not on the time spent working with industry. On the other hand, physical resources had a consistently negative effect. Financial research resources had mixed effects. Indirect financial research resources – the amount of R&D funding coming into a department – only influenced the time an individual researcher spent working with industry. Direct financial research resources from government grants positively influenced whether a researcher was active collaboration with industry, while industry grants significantly increased the time spent working with industry. These findings show that it is essential to determine the goals, objectives, and strategies (i.e., the mandate of the policy) in order to determine what resources are needed to support them.

In 1979, Montjoy and O'Toole pointed out that the success of policies was dependent on both the clarity of the mandate and the availability of resources. This study shows that it is not just the overall availability of resources, but the type of resources and whether they positively contribute to the accomplishment of specific objectives. For instance, the models in this study only looked at one of the main activities of research universities: research. They provide no indication of the effect of departmental research resources on the other missions of universities, namely teaching and service. Further exploration of the effects of resources is certainly warranted in light of the findings here. For instance, how do departmental research resources influence collaboration with other academics and University Research Center affiliation? Do researchers with access to fewer departmental research resources become affiliated with URCs for different reasons than those from relatively richer departments? Are researchers in departments with greater research resources under pressure to acquire more resources?

These results also indicate that research resources and departmental prestige should be taken as complex constructs. Much of the work assessing the quality and prestige of doctoral (research) programs does so based on the resources available within a department (i.e., the number of faculty members, number of graduate students, amount of Federal R&D expenditures, etc.) (Hagstrom, 1971; Jordan, Meador, et al., 1988; Meyer and Rowan, 1991), but then creates a uni-dimensional ranking (see for instance, Cartter, 1966; Jones, Lindzey, et al., 1982; Goldberger, Maher, et al., 1995; National Research Council, 2010). Using uni-dimensional assessments of program prestige rankings to determine the influence of an academic department on a researcher, while certainly convenient, really fails to capture what it is it about the department and its research resources that promote academic productivity and success. The results of Chapter 3 show that the people one works with are, in fact, essential to one's success, at least for industrial involvement activities.

Prestigious departments are at the center of research networks (Matkin, 1990). Thus, the prestige of a department can be considered a form of social capital (Hevenstone, 2008). Therefore, the research in this dissertation supports previous research indicating that departmental prestige of early academic appointments and post-docs is influential in career advancement (Long and McGinnis, 1981; Burris, 2004; Su, 2010), but it also suggests a possible reason why. Prestigious departments provide researchers with networks of colleagues – social, scientific and technical capital – that goes with the researcher (Dietz and Bozeman, 2005). The influence of these human resources is strong in establishing the academic standards and patterns of behavior that successful academic adhere to.

Technology Transfer

In the past quarter century, there has been increasing interest in technology transfer and the role that universities can play in promoting industrial competitiveness and prosperity (Boardman and Corley, 2008; Clark, 2009; Ponomariov and Boardman, 2010). University research has played an important role in creating many new products and industrial sectors, including: aerospace, telecommunications, electronics, transportation and logistics, lasers, pharmaceutical, instruments, and metal industries (Rosenberg and Nelson, 1994). However, the development of new commercial products from scientific research and technology is not a simple process. The nature of technology and innovation means that participants must devote substantial resources to develop, absorb, and improve technology for commercial applications (Mansfield and Lee, 1996; Grossman, Reid, and Morgan, 2001; National Academy of Engineering, 2003). Innovation requires both the transfer of knowledge and the application of this knowledge. The principal form of technology transfer from universities to industry are through human capital (Reddy and Zhao, 1990). That is, through university graduates.

Another important source of technology transfer is through cooperative research and collaboration (Abramson, Encarnação, Reid, and Schmoch, 1997). One of the major aims of U.S. Science and Technology policy since the 1980s has been to encourage technology transfer from universities to industry. Numerous laws,[20] policies, and programs have been enacted to promote industry-university collaboration and industrial involvement (Abramson, Encarnação, et al., 1997). U.S. researchers have grown more favorable towards closer university-industry collaboration (Lee, 1996). Thus, university-industry collaborations have become an increasingly popular way to transfer technology and to develop technologies for commercial applications.

Companies collaborate as a way to obtain access to new technologies and technical expertise (Behrens and Gray, 2001). University and government researchers participate in collaborations to promote technology transfer and to gain access to industrial knowledge (Zieminski and Warda, 1999). University researchers also want to increase the likelihood of a financial return on their discoveries and being directly involved in any further development (Link, Siegel, and Bozeman, 2007). University-industry collaborations increase the likelihood of the successful development of

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[20] For example, Bayh-Dole Act, Economic Recovery Tax Act of 1981 and 1986; National Cooperative Research Act of 1984

commercial products from university research since private corporations are able to guide development with their market orientation, as opposed to researchers attempting to push a technology that is developed in a university laboratory without a clear concept of the marketable application for which it can be used (Zieminski and Warda, 1999).

However, collaborations between the sectors can bring the two different cultures into conflict and create barriers to success. Merger and acquisition failures are frequently blamed on an inability of the two organizational cultures to integrate (Zieminski and Warda, 1999). The private sector is looking for ideas and readily applicable technology to incorporate into its operations and processes, while public sector researchers are often driven by the science itself and the quality of their work. Academics are motivated to disseminate their research into the scientific community in which they belong, while businesses are primarily concerned with control over knowledge (Schein, 1988). Private enterprises "value timeliness, speed, and flexibility" (Link and Siegel, 2005), whereas academic researchers are much more motivated by the discovery process itself (Link and Siegel, 2005, p. 173). The vast majority of academic researchers do not engage with industry in any way. Technology transfer activities are typically concentrated in a few departments, rather than being wide-spread (Bruhn, 2000; Bercovitz and Feldman, 2003). Therefore, more effective technology transfer activities require leveraging researchers in those academic disciplines which have a greater propensity to be involved with industry. As the results of the models in this dissertation show, engineers are more likely to spend time working with industry, to be a resource for industry, and to actively engage with industry than are scientists. In addition, researchers that work with engineers in engineering-dominated URCs are more likely to be active collaboration with industry. Regardless of whether the reason for this outcome is the result of individual work preferences and self-selecting into this type of URC or the influence of the engineers, the results show that engineering-dominated URCs do lead to greater industrial involvement.

Engineers make up only 11.1 percent of faculty members, despite being 17.1 percent of PhD graduates. Of those PhD graduates who choose to work in industry, 55.4 percent are engineering graduates, creating stronger professional networks between academic engineers and industrial engineers. Thus, engineers provide a strong interface between academia and industry.

Policies and incentives designed to increase technology transfer and industrial collaboration should consider leveraging engineers more and allocating greater financial resources to this field. Currently, engineering fields receive 15.1 percent of federal R&D funds in academic institutions. Other sources of funding allocate a larger share to engineering (15.7 percent). Results from Chapter 3 show that department financial research resources have a positive influence on the time spent working with industry, while having direct governmental support positively influences active collaboration with industry. Providing additional funding may provide a means for greater graduate student support and collaboration. Leveraging researchers in academic disciplines more predisposed to work with industry were easier than trying to promote this behavior in academic disciplines less inclined to it.

The differences between different academic disciplines should be investigated further, particularly with respect to the differences between life scientists and physical scientists. There is some evidence that physical scientists may be more like engineers with respect to industrial involvement than they are to life scientists.

An additional difficulty that needs consideration in technology transfer is that the industrial application of new technologies necessarily involves the demonstration and market delivery stages of commercial product development. These often involve individuals from multiple disciplines working together (e.g., scientists, engineers, finance, law, marketing). Like interdisciplinary research within universities, technology transfer and university-industry involvement requires crossing boundaries. The cultures and expectations of organizations within and across sectors are often very different and can result in obstacles and delays to achieving their goals. They can also lead to the failure of the venture altogether.

Research-intensive universities in all industrialized countries have been actively promoting technology transfer and the commercialization of research (Abramson, Encarnação, et al., 1997) in an effort to improve national competitiveness and prosperity. However, the primary research output remains new knowledge that is disseminated through publication and conferences (Geiger, 1990; Bozeman and Boardman, 2003). While independent research centers and institutes have become common-place as avenues for facilitating industry involvement and interdisciplinary research (Geiger, 1990; Abramson, Encarnação, et al., 1997; Bozeman and Boardman, 2003), the home department is still an extremely powerful influence on researchers, as the findings in this dissertation show. Academic socialization and departmental research resources can encourage or dissuade particular behavior. Government and institutional policies that conflict with these influences may prove unsuccessful. Thus, an improved understanding of the factors that motivate researchers may help policymakers and administrators to design more effective policies and incentives.

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Appendix A: RVM Survey

Codebook

This section includes variable name, frequency, and other descriptive statistics for each survey item (in blue, bold font). This information is incorporated into the below copy of the actual 2004-2005 RVM survey, which has been modified somewhat for formatting purposes (though content-wise it is identical to that which RVM sent to the sample).

INFORMED CONSENT FORM

You are being asked to volunteer for a research project. The research value mapping study seeks information about the careers and research experiences of scientists and engineers working in the nation's universities. The study's purpose is to increase our understanding of scientific collaboration, grants and contracts, career trajectories and personal and professional characteristics.

This study is being conducted by a team of researchers at the Georgia Institute of Technology (Georgia Tech) through funding provided by the National Science Foundation (NSF) and the U.S. Department of Energy (DOE). The contents of the study – including this survey and its questions – represent the work of the Georgia Tech research team (not the NSF or the DOE). Neither federal agency was provided information about who participated in the survey. All data were held at Georgia Tech.

There is no direct benefit to you by participating. There are no foreseeable risks to you. You will not be paid nor is there any cost to you by participating.

The survey is for scientific purposes and individual data will not be analyzed. All analyses were conducted at the aggregate level. Your responses will remain confidential and – in accordance with the Privacy Act – we will not release data publicly that will enable others to infer your identity. We estimate that the questionnaire will take approximately 30 minutes to complete. Taking part in this study is completely voluntary. If you have questions about this research or questionnaire, please contact the project manager:

<u>Project Director:</u>
Barry Bozeman
Regents' Professor of Public Policy
RVM Program
School of Public Policy
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<u>Assistant Project Director:</u>
P. Craig Boardman
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(404) 385-4611

If you do not wish to take part, you will have no penalty. You may stop taking part at any time. If you have questions about this research, the questionnaire, or your rights in completing this questionnaire, please call or write:

Alice Basler
Office of Research Compliance
Georgia Institute of Technology
Atlanta, GA 30332-0420
Voice (404) 894-6942 Fax (404) 385-0864

If you have read the statement above and consent to participate, check the box below and proceed to the next page. If you do not wish to participate, simply stop here. We thank you for your interest.

☐ **I have read the above statement and grant my informed consent.** **CONSENT (n=2086; "1"=1320, "0"=766; mean=.63)**

☐ **Please inform me of results of this study** **INFORM (n=2086; "1"=803, "0"=1283; mean=.38)**

Section I. Research Grants

1. If you spend any time writing or participating in the preparation of proposals for contracts or grants, please indicate your agreement or disagreement with the statements below.

☐ Thus far, I have not participated in the preparation of grants or contract proposals

[Please go to the next question] **NOPARTGR (n=2086; "1"=52, "0"=2034; mean=.02)**

	Strongly Agree "4" ▼	Agree Somewhat "3" ▼	Disagree Somewhat "2" ▼	Strongly Disagree "1" ▼
I feel that my administrative superiors expect me to Pursue grants and contracts	☐	☐	☐	☐
I sometimes pursue grants and contracts that are not of great interest to me……………………………………	☐	☐	☐	☐
Generally, I enjoy preparing research proposals………	☐	☐	☐	☐
Writing proposals is a formal requirement for my job …	☐	☐	☐	☐

GRANT01 (n=2015; mean=3.86), valid %/freq: 88.7/1787 9.2/186 1.5/31 .5/11

GRANT02 (n=2008; mean=2.3), valid %/freq: 9.4/189 37.2/746 27.3/548 26.1/525

GRANT03 (n=2009; mean=2.57), valid %/freq: 13.8/278 43.3/870 29.3/588 13.6/273

GRANT04 (n=1996; mean=3.08), valid %/freq: 48/959 25.2/502 13.8/275 13/260

The primary reason for I prepare research proposals is to support the research topics that are of greatest intellectual and professional interest to me…………….. ☐ ☐ ☐ ☐
GRANT05 (n=2009; mean=3.49), valid %/freq: 61.1/1228 29.1/584 7.9/159 1.9/38

The ability to succeed in grants and contracts is (or was) important to my tenure and promotion………………..... ☐ ☐ ☐ ☐
GRANT06 (n=2005; mean=3.67), valid %/freq: 75.9/1522 17/341 4.9/99 2.1/43

A major motivation for my preparing proposals is to support graduate students……………………………… ☐ ☐ ☐ ☐
GRANT07 (n=2010; mean=3.37), valid %/freq: 56.5/1135 29.5/592 8.6/173 5.5/110

I try to obtain grants or contracts to “buy out” from teaching………………………………………………….. ☐ ☐ ☐ ☐
GRANT08 (n=2003; mean=1.79), valid %/freq: 7.8/157 15.5/311 24.9/499 51.7/1036

I try to obtain grants or contracts for salary funding…… ☐ ☐ ☐ ☐
GRANT09 (n=2006; mean=2.78), valid %/freq: 27.8/557 39.3/788 15.7/315 17.2/346

2. Currently, what percentage of your work time, if any, is supported by government-sponsored grants, contracts and cooperative agreements?

_____ % of work time supported by government-sponsored grants, contracts, and cooperative agreements

TIMEGOVT (n=2085; mean=20.05; range=0-100)

3. How many students and postdocs, if any, are currently supported by grants or contracts on which you are PI?

Number of undergraduate students supported currently: ☐
STDSUNDE (n=2084; mean=1.22; range=0-50)

Number of masters students supported currently: ☐
STDSMAST (n=2085; mean=.84; range=0-20)

Number of doctoral students supported currently: ☐
STDSPHDS (n=2085; mean=1.71; range=0-25)

Number of postdoctoral researchers supported currently: ☐
STDSPOST (n=2085; mean=.49; range=0-30)

4. *If you are currently supported by grants or contracts*, whether as principal investigator (PI), co-PI or affiliated researcher, please indicate the source of this support *[Please check all that apply]:*

☐ I am not currently supported by grants or contracts. **[Please go to the next question] “0”**

☐ I am currently supported by grants or contracts from the following sources: **“1”**

NOGRANTS (n=2035; “1”=1599, “0”=436; mean=.79)

____

____

5. Have you had any working relations with private companies during the past 12 months? *[Please mark one box]*

☐ No **[Please proceed to Section II] "0"**

☐ Yes **"1"**
WORKCOMP (n=2043; "1"=952, "0"=1091; mean=.47)

***During the past twelve months*, I have worked with one or more private companies in the following capacities:**

☐ Persons from a private company have asked for information about my research and I have provided it.
WORKREL01 (n=2086; "1"=684, "0"=1402; mean=.33)

☐ I contacted persons in industry asking about their research or research interests.
WORKREL02 (n=2086; "1"=351, "0"=1735; mean=.17)

☐ I served as a formal paid consultant to an industrial firm.
WORKREL03 (n=2086; "1"=329, "0"=1757; mean=.16)

☐ I helped place graduate students or post-docs in industry jobs.
WORKREL04 (n=2086; "1"=458, "0"=1628; mean=.22)

☐ I worked at a company with which I am owner, partner or employee.
WORKREL05 (n=2086; "1"=66, "0"=2020; mean=.03)

☐ I worked directly with industry personnel in work that resulted in a patent or copyright
WORKREL06 (n=2086; "1"=99, "0"=1987; mean=.05)

☐ I worked directly with industry personnel in an effort to transfer or commercialize technology or applied research.
WORKREL07 (n=2086; "1"=288, "0"=1798; mean=.14)

☐ I co-authored a paper with industry personnel that has been published in a journal or refereed proceedings.
WORKREL08 (n=2086; "1"=270, "0"=1876; mean=.13)

☐ Other (Please specify) ______________________________
WORKREL09 (n=2086; "1"=207, "0"=1879; mean=.10)

Section II. Research Collaboration

6. If we define research collaboration as "working closely with others to produce new scientific knowledge or technology." In your <u>current</u> career stage, how important are each of the following factors in your decisions to collaborate? *[Please check one box in each row]*

Not Important "1"	Very Important "4"	Somewhat Important "3"	Somewhat Unimportant "2"

▼	▼	▼		▼
Length of time I have known the person **COLLAB01 (n=2053; mean=2.59), valid %/freq:**	☐ **10.4/214**	☐ **49.5/1016**	☐ **28.5/585**	☐ **11.6/238**
Responding to requests of my administrative superiors **COLLAB02 (n=2041; mean=1.76), valid %/freq:**	☐ **2.8/57**	☐ **20.2/412**	☐ **27.4/560**	☐ **49.6/1012**
Interest in helping junior colleagues **COLLAB03 (n=2036; mean=2.71), valid %/freq:**	☐ **17.3/352**	☐ **49.7/1011**	☐ **19.4/394**	☐ **13.7/279**
Desire to work with researchers who have strong scientific reputations **COLLAB04 (n=2038; mean=3.09), valid %/freq:**	☐ **35.9/731**	☐ **43.7/890**	☐ **13.6/278**	☐ **6.8/139**
Desire to work with researchers whose work skills and knowledge complement my own **COLLAB05 (n=2055; mean=3.77), valid %/freq:**	☐ **80/1643**	☐ **17.9/367**	☐ **1.3/27**	☐ **.9/18**
Quality of my previous collaborations with the person **COLLAB06 (n=2049; mean=3.66), valid %/freq:**	☐ **73.3/1502**	☐ **21.9/448**	☐ **2.6/54**	☐ **2.2/45**
Interest in helping graduate students **COLLAB07 (n=2039; mean=3.15), valid %/freq:**	☐ **38.4/783**	☐ **44.1/900**	☐ **11.3/231**	☐ **6.1/125**
The extent to which working with the individual is fun or entertaining (apart from the work itself) **COLLAB08 (n=2050; mean=2.78), valid %/freq:**	☐ **22.7/465**	☐ **44.7/916**	☐ **21/430**	☐ **11.7/239**
Desire that the collaborator be highly fluent in my native language **COLLAB09 (n=2043; mean=2.00), valid %/freq:**	☐ **6.8/138**	☐ **24.6/503**	☐ **30.7/628**	☐ **37.9/774**
Desire to work with researchers from the same country of origin **COLLAB010 (n=2037; mean=1.32), valid %/freq:**	☐ **.7/14**	☐ **4/81**	☐ **21.7/442**	☐ **73.6/1500**
The collaborator should have a strong work ethic **COLLAB11 (n=2048; mean=3.51), valid %/freq:**	☐ **58.3/1194**	☐ **35.5/728**	☐ **4.7/97**	☐ **1.4/29**
The ability of the collaborator to stick to a schedule	☐	☐	☐	☐

COLLAB12 (n=2046; mean=3.16), **valid %/freq:**
32.3/661 **53.8/1101** **11.1/228** **2.7/56**

Practices for assigning credit (e.g. order of authorship) ☐ ☐ ☐ ☐
COLLAB13 (n=2036; mean=2.47), **valid %/freq:**
13.7/279 **38.9/791** **28.4/579** **19/387**

7. For the past twelve months, please tell us the approximate number of people in each of the following categories with whom you have had research collaborations:

Number of male university faculty:
MALEFACU (n=2085; mean=4.64; range=0-770)

Number of female university faculty:
FEMAFACU (n=2085; mean=1.57; range=0-710)

Number of current male graduate students:
MALEGRAD (n=2085; mean=2.68; range=0-200)

Number of current female graduate students:
FEMAGRAD (n=2085; mean=1.42; range=0-75)

Others (both male or female):
OTHCOLLA (n=2082; mean=1.71; range=0-150)

8. Scientists work on their own and in research groups. For the past twelve months, could you please estimate the percentage of your research-related work time devoted to each of the following categories. *[Percentages should add up to 100; your best estimate will do]*

Work Setting	**Percentage of Research Time**
Working alone (on research that at no point includes a collaborator) **RESEAR01 (n=2083; mean=21.66; range=0-100)**	%
Working with researchers and graduate students in my immediate work group, laboratory, or research center **RESEAR02 (n=2083; mean=42.55; range=0-100)**	%
Working with researchers in my university, but outside my immediate work group, laboratory or research center **RESEAR03 (n=2082; mean=10.48; range=0-100)**	%
Working with researchers who reside in nations other than the U.S. **RESEAR04 (n=2082; mean=5.25; range=0-100)**	%
Working with researchers in U. S. universities other than my own **RESEAR05 (n=2083; mean=10.15; range=0-100)**	%
Working with researchers in U. S. industry **RESEAR06 (n=2083; mean=2.71; range=0-50)**	%
Working with researchers in U. S. government laboratories **RESEAR07 (n=2083; mean=3.33; range=0-100)**	%
Total	100 %

Section III. Scientific Work Experiences and Values

9. Please indicate the extent to which you agree or disagree with each of the following statements. ***[Please check one box in each row]***

	Strongly Agree **4** ▼	**Agree Somewhat** **3** ▼	**Disagree Somewhat** **2** ▼	**Strongly Disagree** **1** ▼
Worrying about possible commercial applications distracts one from doing good research………………..	☐	☐	☐	☐
SCIVAL01 (n=2008; mean=2.20), valid %/freq:	**8.1/163**	**29.5/593**	**36.7/736**	**25.7/516**
I enjoy research more than I enjoy teaching…………..	☐	☐	☐	☐
SCIVAL02 (n=2016; mean=2.69), valid %/freq:	**19.7/398**	**38.9/785**	**32/646**	**9.3/187**
If you do not teach check here: ☐				
SCIVAL03 (n=2086; “1”=27, “0”=2059; mean=.01)				
Government has too big a role in setting priorities for research………………………………….....	☐	☐	☐	☐
SCIVAL04 (n=2026; mean=2.74), valid %/freq:	**15.7/318**	**47.4/961**	**32.1/651**	**4.7/96**
I'd rather double my citation rate than double my salary……………………………………………….	☐	☐	☐	☐
SCIVAL05 (n=2020; mean=2.24), valid %/freq:	**11.7/236**	**26.3/531**	**36.2/731**	**25.8/522**
My colleagues in my home department appreciate my research contributions…………………………….....	☐	☐	☐	☐
SCIVAL06 (n=2031; mean=2.84), valid %/freq:	**20.1/408**	**51.9/1055**	**19.9/405**	**8.0/163**
I am satisfied with my job…………………………….....	☐	☐	☐	☐
SCIVAL07 (n=2042; mean=3.13), valid %/freq:	**37/756**	**44.3/905**	**13.5/276**	**5.1/105**
I think I am paid about what I am worth in the academic market……………………………………….	☐	☐	☐	☐
SCIVAL08 (n=2035; mean=2.49), valid %/freq:	**15.3/311**	**36.4/740**	**30.5/621**	**17.8/363**
In government decisions about research funding, the scientist's intellectual curiosity should be much <u>less</u> important than the potential of the research to improve people's lives……………………………………………….	☐	☐	☐	☐
SCIVAL09 (n=2010; mean=2.26), valid %/freq:	**6.5/131**	**30.9/622**	**44.8/901**	**17.7/356**

10. For the most recent full academic term, please indicate the average number of hours per week devoted to each of the activities below ***[Your best estimate will do].***

Work Activity	**Average Hours Per Week**
Writing or developing proposals for grants and contracts **TIMEAL01 (n=2081; mean=4.63; range=0-50)**	
Conducting research related to grants and contracts **TIMEAL02 (n=2081; mean=11.76; range=0-140)**	

Work Activity	Average Hours Per Week
Conducting research not related to grants and contracts **TIMEAL03 (n=2081; mean=5.40; range=0-140)**	
Administering grants and contracts **TIMEAL04 (n=2081; mean=2.44; range=0-30)**	
Teaching undergraduate students (including preparation time and meeting outside class) **TIMEAL05 (n=2081; mean=10.68; range=0-140)**	
Teaching graduate students (including preparation time and meeting outside class)**TIMEAL06 (n=2080; mean=6.18; range=0-84)**	
Advising graduate and undergraduate student advising for curriculum and job placement **TIMEAL07 (n=2080; mean=2.6; range=0-30)**	
Professional and community service work (not part of university service) **TIMEAL08 (n=2081; mean=2.53; range=0-50)**	
University, departmental or research center service and committee work **TIMEAL09 (n=2081; mean=5.19; range=0-65)**	
Paid consulting **TIMEAL10 (n=2080; mean=.52; range=0-20)**	

Section IV. Center Affiliations

Definition: A university research center is a "research institution that has five or more faculty and postdoctoral researchers and includes participants from more than one discipline and more than one academic department."

- ☐ **Considering the above definition, I am not affiliated with a university research center [Please proceed to Section V] "0"**

- ☐ **I am affiliated with a university research center. The name of the Center I am affiliated with is [Note: if affiliated with more than one, list affiliation most important to you]: "1"**

CTRAFF (n=2028; "1"=753, "0"=1275; mean=.37)

____

____

11. During what year did you affiliate with the center?

______ Year affiliation began

CENTYEAR (n=743; mean=1996; range=1963-2004)

12. Affiliation with a university research center can have important positive and negative effects on one's career. Below, please mark the position on the scale that seems to best fit your views about the career impacts of your research center affiliation.

Very Negative	No Effect	Very Positive

▼ ▼ ▼

Opportunities for consulting -3 -2 -1 0 +1 +2 +3
CENTAFF01 (n=765; mean= .39) val. %/freq.: 1.2/9 2.0/15 .8/6 5.1/498 20/153 6.1/47 4.8/37

Opportunities for research grants or contracts:

From government agencies -3 -2 -1 0 +1 +2 +3
CENTAFF02 (n=767; mean=1.51) val. %/freq.: .8/6 .3/2 .9/7 18.5/142 27.2/209 29.7/228 22.6/173

From industry -3 -2 -1 0 +1 +2 +3
CENTAFF03 (n=762; mean= .72) val. %/freq.: 1.4/11 .9/7 1.2/9 49.1/374 24.7/188 13.3/101 9.4/72

Ability to publish journal articles -3 -2 -1 0 +1 +2 +3
CENTAFF04 (n=770; mean=.93) val. %/freq.: .6/5 .5/4 1.7/13 42.6/328 23.6/182 18.6/143 12.3/95

Ability to publish interdisciplinary journal articles -3 -2 -1 0 +1 +2 +3
CENTAFF05 (n=769; mean= 1.18) val. %/freq.: .4/3 .1/1 .5/4 33.9/261 26.7/205 21.3/164 17/131

Ability to publish research that is more applied -3 -2 -1 0 +1 +2 +3
CENTAFF06 (n=767; mean= .80) val. %/freq.: .7/5 4/3 1.8/14 50.5/387 19.3/148 17.2/132 10.2/78

Ability to patent or commercialize research findings -3 -2 -1 0 +1 +2 +3
CENTAFF07 (n=762; mean= .35) val%/freq.: 1.4/11 .9/7 .9/7 69.9/533 15/114 8.1/62 3.7/28

Research autonomy -3 -2 -1 0 +1 +2 +3
CENTAFF08 (n=761; mean= .37) val. %/freq.: 1.6/12 3.7/28 12/91 50.6/385 12.4/94 10.8/82 9.1/69

Likelihood of getting my research proposals approved -3 -2 -1 0 +1 +2 +3
CENTAFF09 (n=765; mean= .89) val. %/freq.: .9/7 0/0 1.6/12 39.7/304 30.3/232 19.7/151 7.7/59

Research collaboration opportunities -3 -2 -1 0 +1 +2 +3
CENTAFF10 (n=769; mean=1.87) val. %/freq.: .4/3 .1/1 .1/1 7.8/60 24.2/186 37.5/288 29.9/230

Access to new equipment and facilities -3 -2 -1 0 +1 +2 +3
CENTAFF11 (n=769; mean=1.55) val. %/freq.: .7/5 .8/6 .7/5 18.9/145 25.6/197 26.5/204 26.9/207

Reduced teaching load -3 -2 -1 0 +1 +2 +3
CENTAFF12 (n=768; mean= .19) val. %/freq.: 3.5/27 1.7/13 2.7/21 72.4/556 8.7/67 6.1/47 4.8/37

Impact on tenure -3 -2 -1 0 +1 +2 +3
CENTAFF13 (n=760; mean= .56) val. %/freq.: 1.4/11 .9/7 2.8/21 52.5/399 25/190 12.4/91 5.4/41

Ability to recruit or retain students -3 -2 -1 0 +1 +2 +3
CENTAFF14 (n=762; mean=1.07) val. %/freq.: .4/3 1.2/9 1/8 28.7/219 36.6/279 21.5/164 10.5/80

Ability to place students -3 -2 -1 0 +1 +2 +3
CENTAFF15 (n=755; mean= .9) val. %/freq.: .4/3 0/0 1.1/8 42.6/322 28.3/214 18.5/140 9.0/68

My overall satisfaction working at this university -3 -2 -1 0 +1 +2 +3
CENTAFF16 (n=767; mean=1.41) val. %/freq.: 1.3/10 2/15 2.9/22 13/100 28.4/218 33.5/257 18.9/145

13. What percentage of your salary, if any, comes from the center(s) with which you are affiliated? [*Include any salary from center-based grants and contracts*]

______ % of my salary compensated by center(s)
CENTSALAR (n=2085; mean=5.34; range=0-100)

14. What percentage of your research work time is allocated to center-related work?

______ % of research work time devoted to center-related work
CENTWORKT (n=2082; mean=11.31; range=0-100)

Section V. Demographic Characteristics

15. Have you ever been a university-based post-doctoral researcher or fellow? If so, please provide the years during which you were a postdoc.

☐ No, I have never been a postdoc. **"0"**

☐ Yes **"1"**, I was a postdoc from ___postdocyb______ to __postdocye_______.

POSTDOC (n=2041; "1"=955, "0"=1086; mean=.47)

POSTDOCYB (n=949; mean=1986; range=1952-2003); POSTDOCYE (n=949; mean=1989; range=1954-2005)
16. Are you: ☐ Male **"1"** ☐ Female **"0"**
GENDER (n=2031; "1"=979, "0"=1052; mean=.48)

17. In what year were you born? 19______
BORNYR (n=2022; mean=56.38; range=22-77)

18. In what year did you *[Leave items blank if they are not applicable]*:

Year

Complete your Ph.D. ________
PHDYR (n=2033; mean=1986; range=1951-2003)
Start in a tenure track position ________
TETRAKYR (n=1980; mean=1989; range=1952-2004)

Obtain tenure ________
TENUREYR (n=1437; mean=1990; range=1954-2005)
Attain rank of Associate Professor ________
ASSOCYR (n=1432; mean=1990; range= 1954-2004)
Attain rank of Full Professor ________
FULLPRYR (n=920; mean=1992; range=1960-2005)

19. What is the discipline of your doctoral degree (e.g. physics, chemistry, electrical engineering)?

☐ Check here if you do not have a Ph.D. degree **"1" if checked**
PHDDGREE (n=2086; mean=.02; "1"=32, "0"=2054)

Discipline of Ph.D. degree: ____________________________________
PHDDISCP (n=2086)

20. What is your racial/ethnic identification?

- ☐ Asian **ASIAN (n=2086; mean=.1; "1"=218, "0"=1868)**
- ☐ Black **BLACK (n=2086; mean=.03; "1"=64, "0"=2022)**
- ☐ Hispanic **HISPANIC (n=2086; mean=.04; "1"=76, "0"=2010)**
- ☐ Native American **NATIVEAM (n=2086; mean=0; "1"=7, "0"=2079)**
- ☐ White **WHITE (n=2086; mean=.79; "1"=1653, "0"=433)**
- ☐ Other [*Please specify*] **OTHRACYN (n=2086; mean=.02; "1"=36, "0"=2050)**

____________________________________ **OTHRACE (string)**

21. What is your <u>current</u> citizenship status?

- ☐ Native born U.S. citizen **USCITZ (n=2086; mean=.72; "1"=1500, "0"=586)**
- ☐ Naturalized U.S. citizen **NATUSCIT (n=2086; mean=.14; "1"=283, "0"=1803)**
- ☐ Non U.S. citizen with a permanent U.S. resident visa **PERMVISA (n=2086; mean=.09; "1"=178, "0"=1908)**
- ☐ Non U.S. citizen with a temporary U.S. resident visa **TEMPVISA (n=2086; mean=.04) "1"=86, "0"=2000)**

22. [*IF U.S. NATURALIZED CITIZEN OR NON U.S. CITIZEN*], of which country are (were) you a citizen?

____________________________________ **COUNTRY (string)**

23. <u>Currently</u>, are you either married or living with a domestic partner?

☐ Yes ☐ No **[If No, please go to Question 26]**
MARRIED (n=2038; mean =.85; "1"=1731, "0"=307)

24. Which of the following best describes your spouse or partner's <u>current</u> position?

- ☐ Full time homemaker or family caregiver

  SPOUJOB1 (n=2086; mean = .17; “1”=355, “0”=1731)
- ☐ Private business or professional (e.g. lawyer, physician, accountant)

  SPOUJOB2 (n=2086; mean=.18; “1”=384, “0”=1702)
- ☐ Government or nonprofit employee

  SPOUJOB3 (n=2086; mean=.06; “1”=124, “0”=1962)
- ☐ University or college faculty or researcher

  SPOUJOB4 (n=2086; mean=.25; “1”=513, “0”=1573)
- ☐ Other university position

  SPOUJOB5 (n=2086; mean=.06; “1”=116, “0”=1970)
- ☐ Other [*Please specify*]

  SPOUJOB6 (n=2086; mean=.12; “1”=256, “0”=1830)

  ________________________________ **SPOUOTHR (string)**

25. Currently, do you have children living with you as part of your family? If so, how many?

Number of children living with you: ______
CHILDREN (n=2085; mean=.83; range=0-10)

26. What is your parent’s highest level of formal education? *[Please check one box in each column]*

	Father	Mother
Not a high school graduate **1**	☐	☐
High school graduate **2**	☐	☐
Attended college, but did not graduate **3**	☐	☐
College graduate (B.A., B.S.) **4**	☐	☐
Post graduate **5**	☐	☐
Not sure/Don’t know **99**	☐	☐

FATHREDU (n=2034; “1”=294 at 14.5 percent, “2”= 342 at 16.8 percent, “3” = 185 at 9.1 percent, “4” = 479 at 23.5 percent, “5” = 728 at 35.8 percent, “99” = 6 at .3 percent)

MOTHREDU (n=2033; “1”=257 at 12.6 percent, “2”= 545 at 26.8 percent, “3” = 256 at 12.6 percent, “4” = 527 at 25.9 percent, “5” = 439 at 21.6 percent, “99” = 9 at .4 percent)

27. To develop further information about career histories we are also collecting curriculum vita (CV) of our survey respondents. We hope that you will provide us yours. *We will use your CV only for research purposes and will not examine individual-level data*. If you would like to see an example of the ways we use CV’s for research please go to http://www.rvm.gatech.edu/cv

- ☐ I am including my CV with this survey

  CVSURVEY (n=2086; mean=.19; “1”=398, “0”=1688)

☐ I am sending my CV via a separate email [*Please send file to* rvm@pubpolicy.gatech.edu]

CVEMAIL (n=2086; mean=.19; “1”=393, “0”=1693)

☐ You can download my CV at:

CVDOWNLO (n=2086; mean=.11; “1”=233, “0”=1853)

[Please give website] ____

CVADDRES (string)

28. Regardless of how happy or unhappy you are with your scientific career, what is the single most important factor *(other than more research funding or a higher salary)* that, if it could be changed, would increase your satisfaction with your work? HAPPYFAC (string)

Thank you for taking your time to complete this questionnaire. Your assistance in providing this information is very much appreciated. If there is anything else you would like to tell us about any of the topics covered by this questionnaire, please do so in the space provided below: Comments y/n (string)

Appendix B: Factor Analysis for Departmental Research Resources

Several major studies have endeavored to evaluate the quality and effectiveness of doctoral research departments at universities. The first major study was undertaken in 1924 by the president of the Miami University in Ohio, Raymond Hughes, who attempted to measure the quality of graduate programs in 38 of the 65 universities offering doctorate degrees in order to provide some guide for the undergraduate students at his university. He had the faculty at Miami University prepare a list of those scholars that they felt were distinguished nationally. Hughes then sent questionnaires to each of these distinguished scholars, trying to gauge their opinion about the quality of graduate education in the United States. Hughes used the results of the questionnaire to develop at reputational ranking of doctoral programs (Grayson, 1993). Hughes repeated the study in 1934, expanding his sample to 59 research universities.

In 1957, Hayward Keniston made another attempt to evaluate doctoral programs. The purpose of his study was to compare the University of Pennsylvania, where Keniston was the Dean of Graduate Studies, to similar institutions. Keniston surveyed the department chairs from 25 of the 62 AAU institutions, asking them to evaluate the quality of the PhD work and faculty scholarship and then to rate the strongest departments in their respective fields (Cartter, 1966; Goldberger, Maher, et al., 1995).

The next major study of research doctorate departments was the seminal report by Allen Cartter, *An Assessment of Quality in Graduate Education*, published in 1966. Cartter was appointed by the American Council on Education to head the Commission on Plans and Objectives for Higher Education and report on the quality of higher education instruction. Cartter studied the doctoral programs at 106 institutions in 29 academic fields. In total, he surveyed 5,367 academic professionals and asked them to rank the institutions by the quality of the graduate faculty and the effectiveness of their doctoral programs in their respective fields (Goldberger, Maher, et al., 1995). In determining quality, Cartter asked the respondents to focus on the research capabilities and academic achievements of the current faculty, as well as the access to facilities and graduate students. Cartter coupled the survey results with objective institutional measures, such as volumes in the library, to rank the programs. He explicitly did not aggregate the results to the institutional level, insisting that this type of measure was misleading as institutions do not equally invest in all programs and departments and, therefore, any institutional ranking would necessarily involve subjective judgments about the relative importance and weightings of individual programs. In 1970, Roose and Andersen replicated Cartter's study, though they tried to de-emphasize the ranking of the evaluations in their report.

The studies by Hughes (1924), Keniston (Cartter, 1966), Cartter (1959), and Roose and Andersen (1966) all relied on the evaluations of faculty members within a discipline to assess the quality of programs. These studies were widely viewed as subjective (1970). Therefore, attempts were made to develop objective and consistent measures for evaluating doctoral programs. The National Research Council undertook the assessment of doctoral programs. They published reports in 1982, 1995, and most recently, in the fall of 2010. The NRC rankings of doctoral programs are focused on research and student outcomes.

The 1982 NRC report, An Assessment of Research-Doctorate Programs in the United States: Mathematical and Physical Sciences, tried to address the criticisms of the Cartter study. The Committee surveyed 2,699 programs in 32 disciplines, including both subjective and objective factors (Dolan, 1976; Jones, Lindzey, et al., 1982). Data on sixteen measures were gathered, including: (1) the number of faculty members; (2) the number of graduates; (3) total number of full-time and part-time graduate students; (4) the fraction of program graduates that had some national fellowship or grant; (5) median number of years from first enrollment to receipt of doctorate; (6) total number of commitments upon PhD completion to post-doctoral employment planned by graduate students; (7) total number of commitments upon PhD completion to post-graduation employment planned by graduate students; (8) the mean peer rating of scholarly quality of the program faculty; (9) the mean peer rating of the effectiveness of the program in educating research scholars/scientists; (10) the mean peer rating of the improvement in program quality in last five years; (11) the mean peer rating of the evaluator's familiarity with the work of program faculty; (12) a composite index of library size; (13) the percentage of faculty having research grants; (14) the total expenditures for R&D activities; (15) the number of articles published by the faculty; and (16) the estimated overall influence of the published articles (Jones, Lindzey, et al., 1982). Notwithstanding the Committee's attempt to be thorough and objective, the report was widely criticized.

The NRC report did provide a foundation for empirical research linking specific factors with faculty and program outcomes. Beginning in the 1980s, Larry Leslie and several of his students, began to develop and test a measure of research activity that they termed a Research Activity Index (RAI) score (Jones, Lindzey, et al., 1982, pp. 15-29). The purpose of the RAI was to provide a multi-dimensional summary statistic of numerous input and process variables related to research (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992), that would provide a better measure than simply looking at the total R&D expenditures at an institution, which excluded other factors important for research, including the number of doctoral degrees awarded by an institution, the research training provided to graduate students, and the library resources available (Ashton, 1984, p. 94).

Ashton began by gather data on 26 variables - (1) four year percent change in R&D expenditures; (2) book value of the institution's endowment at the end of year; (3) market value of the institution's endowment at the end of year; (4) the average percentage change in R&D expenditures from 1977-1980; (5) federal government research and development (R&D) expenditures; (6) state and local government R&D expenditures; (7) industry R&D expenditures; (8) institutional R&D expenditures; (9) other source R&D expenditures; (10) total R&D expenditures; (11) total capital expenditures for scientific and engineering facilities and research equipment for research, development, and instruction; (12) federal capital expenditures for research facilities and equipment; (13) all other capital expenditures; (14) full-time faculty members in science and engineering; (15) part-time full-time faculty members in science and engineering; (16) full-time equivalent scientists and engineers; (17) full-time science graduate students; (18) part-time science graduate students; (19) post-doctorates; (20) other non-faculty science doctoral research staff; (21) post-doctorate and other science students; (22) education and general expenditures and mandatory transfers; (23) average faculty compensation; (24) number of PhDs awarded in specific year; (25) academic fields of study; and (26) the Association of Research Libraries (ARL) index.

Through principal component analysis, Ashton identified eleven essential factors research activities: (1) four year percent change in R&D expenditures; (10) total R&D expenditures; (11) total capital expenditures for scientific and engineering facilities and research equipment for research, development, and instruction; (14) full-time faculty members in science and engineering; (15) part-time scientists and engineers; (17) full-time science graduate students; (18) part-time science graduate students; (19) post-doctorates; (20) other non-faculty science doctoral research staff; (24) number of PhDs awarded in specific year; and (26) the Association of Research Libraries (ARL) index.

Groth (1990) replicated Ashton's study at the departmental level, which allowed him to evaluate and rank academic fields. Eight variables were retained in the principal component analysis and used to develop the RAI at the departmental level: (1) total number of doctoral degrees awarded; (2) Total expenditures for R&D from federal sources; (3) Total expenditures for R&D from non-federal sources; (4) total number of full-time faculty scientists and engineers; (5) total number of part-time faculty scientists and engineers; (6) total number of other non-faculty research staff; (7) total number of full-time graduate students; (8) total capital expenditures for scientific and engineering facilities for R&D and instruction from other than federal sources.

The National Research Council made another evaluation of doctoral programs just after the RAI research was completed. The Committee for the Study of Research Doctorate Programs in the United States published a ranking of doctoral programs in 1995, Research-Doctorate Programs in the United States, Report of the Committee Assess Research-Doctorate Programs (Groth, Brown, et al., 1992). The authors noted that there was a strong correlation between the size of a faculty and its reputational ranking on previous studies, but that more empirical research needed to be done exploring the other aspects of scholarly quality of doctoral programs. The Committee gathered data on faculty, students, and doctoral recipients to develop their ranking. In particular, they used the following variables: (1) total number of faculty; (2) percentage of full professors; (3) percentage of faculty with research support; (4) percentage of program faculty publishing between 1988 and 1992; (5) ratio of total number of publications in a specific field between 1988 and 1992 to faculty publications; (6) Gini publication coefficient for concentration of publications between 1988 and 1992; (7) the ratio of total number of program citations between 1988 and 1992; (8) Gini citation coefficient between 1988 and 1992; (9) total number of full-time and part-time students enrolled; (10) percentage of female graduate students; (11) number of PhDs awarded between 1988 and 1992; (12) percentage of PhDs awarded to women; (13) percentage of PhDs awarded to minorities; (14) percentage of PhDs awarded to US citizens and permanent residents; (15) percentage of PhDs having research assistantships as primary form of support; (16) percentage of PhDs having teaching assistantships as primary form of support; (17) median time lapse from enrollment to graduation in years (Goldberger, Maher, et al., 1995).

In their study of institutional prestige and reputation of universities and colleges, Volkwein and Sweitzer (2006) found that there was a high correlation between the NRC faculty reputation ranking and the U.S. News Academic Reputation Ratings with: total faculty publications, publications per faculty member, total citations, citations per faculty member, total R&D expenditures, R&D expenditures per faculty member, average salaries of faculty members, the total faculty size, and the total student enrollment (Goldberger, Maher, et al., 1995, pp. 25-26). In turn, the authors found that these factors were driven by structural characteristics of the institution, including: institution size, university endowment, resource deployment, faculty recruitment policies and salaries.

The most recent attempt by the NRC to evaluate doctoral research programs, A Data-Based Assessment of Research-Doctorate Programs in the United States, was released last fall. Begun in 2003, the survey for the evaluation was taken in late 2005. Twenty-four variables were gathered and used to evaluate and rank doctoral programs, including: (1) number of faculty members; (2) average number of publications (2000-2006) per allocated faculty; (3) Average citations per publication; (4) percentage of faculty with grants; (5) awards per allocated faculty member; (6) percent of first year students with full financial support; (7) average completion ratio benchmarked at 6 years; (7) median time to degree; (8) percent of students with academic plans; (9) average number of PhDs graduated between 2002-2006; (10) percent of interdisciplinary faculty; (11) average GRE scores, 2004-2006; (12) percentage of students with external fellowships; (13) student work space; (14) health insurance; (15) total faculty; (16) allocated faculty; (17) percentage of assistant professors of total faculty; (18) tenured faculty; (19) number of core and new faculty; (20) number of students enrolled; (21) average first year enrollment; (22) percentage of students with research assistantships; (23) percentage of students with teaching assistantships; (24) student activities; and demographic characteristics of faculty and students (Volkwein and Sweitzer, 2006).

Independent of NRC efforts, John Lombardi (Ostriker, Kuh, et al., 2010, pp. 39-45) ranked the American research universities based on nine factors: (1) federal research expenditures; (2) other research expenditures; (3) national academy membership; (4) national awards by faculty; (5) GRE/SAT scores; (6) number of doctorates granted; (7) number of postdoctoral positions; (8) university endowments; and (9) annual private gifts.

Following up the work of Leslie, Ashton, and Groth (Lombardi, Capaldi, Mirka, and Abbey, 2005), Mathies (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992) investigated the institutional factors that lead to increased federal R&D funding at 400 research universities. Mathies used the framework and variables for the RAI, but removed the federal R&D expenditures. In explaining the factors that led to increased federal R&D funding, Mathies used principal component analysis to reduce twenty variables to eleven variables: (1) number of faculty members that are assistant professors; (2) number of faculty members that are associate professors; (3) number of faculty members that are full professors; (4) average faculty salary for assistant professors; (5) average faculty salary for associate professors; (6) average faculty salary for full professors; (7) number of graduate students; (8) expenditures for research equipment; (9) Association of Research

Libraries (ARL) index; (10) whether the university had a hospital/medical school; (11) whether medical degrees were granted. Mathies found that these variables were all positively related to increased federal R&D expenditures at an institution.

Research Resources

Though most of these studies state that they are trying to rank the quality and effectiveness of doctoral programs, many of the measures they are using are, in fact, the resources available to researchers as the basis for evaluation. They are, in essence, trying to determine the underlying research resources which support and encourage greater research quality, productivity, and success.

Latent Variables and Confirmatory Factor Analysis

When looking to define the effect of a latent variable, it is necessary to try to identify and specify the underlying latent variable which the observed variables are being used to represent. This is because each of the observed variables is imperfectly representing the latent variable and observed variables may overlap and misrepresent the effect of the latent variable. Principal Component Analysis (PCA), Exploratory Factor Analysis (EFA), and Confirmatory Factor Analysis (CFA) are all used to identify the underlying latent variable. Though having commonalities, these three methods have different theoretical foundations, which determine methodology, and how the results are to be interpreted.

The Principal Component Analysis used by Ashton, Groth, Leslie et al., and Mathies (Mathies II, 2010) attempts to extract the most influential components of a number of variables by focusing on the variables that contribute the greatest variance in the original set of variables. Thus, PCA tried to reduce the total number of variables while retaining the maximum amount of variance (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992; Mathies II, 2010).

Exploratory Factor Analysis also attempts to reduce a set of variables to a smaller number of underlying, or latent, variables. EFA allows a researcher to look for these underlying factors without needing to specify the number of factors beforehand (Jolliffe, 2002).

Confirmatory Factor Analysis requires the researcher to specify the relationship between the observed variables and the latent factors in advance. The factor is then evaluated by how well it replicates the original covariance matrix of the observed variables (Kim and Mueller, 1978; Brown, 2006). As it is prescribed, CFA requires good theoretical justifications for the relationship between the observed variables and the latent factors. CFA relies on structural equation models (SEM) to develop the factors to determine if the theoretical model fits the data by estimating the parameters and assessing the goodness of fit of the model (Brown, 2006).

In this study, confirmatory factor analysis was used to identify the latent variables comprising the level and quality of the research resources available to researchers to support research productivity because empirical evidence supports the theoretical construction of the factors. In a typical CFA, there were a small number of factors and several variables per factor (Kolenikov, 2009). From the previous empirical research, it is anticipated that there are three underlying factors that are the resources used by researchers: (1) human resources; (2) financial resources; and (3) physical resources.

The table in the appendix shows how the variables used in previous empirical studies are classified.

Human Resources Factor

By far the most frequently used and commonly important variable is the size of the department. Often this is identified as the number of faculty members in the department. However, the number of graduate students and number of PhD recipients are also frequently used (Kolenikov, 2009). The following observed variables were used to compute the latent variable of the Human Resources Factor:

1. The number of faculty members in the researcher's home department.
2. The average number of graduate students in the researcher's home department.
3. The average number of PhD recipients in the researcher's home department.
4. The average number of publications per faculty member in the researcher's home department.
5. The average number of citations per publication in the researcher's home department.

Several studies have shown that larger research departments (measured by the size of the faculty and student enrollment) are more prestigious, academically productive, are cited more often, and have better quality students (Katz, 1980; McCoy, Krakower, et al., 1982; Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992; Mathies II, 2010). This has led researchers to postulate that faculty size itself is the main underlying factor producing these results (Hagstrom, 1971; Meadows, 1974; Long, 1978; Jordan, Meador, et al., 1988, 1989; Blau, 1994 [1973]; Kyvik, 1995; Dundar and Lewis, 1998). One study by King and Wolfle of latent variables of faculty reputational rankings (King and Wolfle, 1987) supports the focus on faculty size as a latent variable. King and Wolfle found that the size of the department was an important indicator of the departmental reputation, as measured in the 1982 NRC study (King and Wolfle, 1987). However, it is not simply the existence of a large number of people in proximity that creates productive researchers. Rather, it is the academic culture and intellectual stimulation that this group of people creates. Johnston (Jones, Lindzey, et al., 1982) found that single researchers in large departments were not sufficient to create well-respected faculty in a subfield. Rather, there needed to be a critical mass of at least four to six researchers, along with supporting graduate student researchers, working together in a specific specialization to be competitive in building an international reputation for the department. Larger departments are more likely to have several faculty members with similar research interests (Johnston, 1994). They are also more likely to attract higher quality researchers (Kyvik, 1995), both because researchers may be attracted to current faculty members, but also because larger departments are more likely to have the resources needed to support eminent scholars. In considering the departmental and institutional factors that support researcher behavior and productivity, it would be preferable also to consider the characteristics that indicate quality in research, such as the average number of publications per faculty member and the average number of citations per publication. Correlation analysis of the number of faculty members and the average publications per faculty members showed a correlation of 0.1295. The average number of citations per publication is correlated with the number of faculty members at 0.1194. Therefore, these variables will also be included in the factor.

Financial Resources

R&D funding are an important research resource and are used in most of the studies discussed above to measure and explain quality and research activity (Dundar and Lewis, 1998). The total R&D expenditures in millions of dollars for each department were used. Thus, no factor analysis is required for this variable.

Physical Resources Factor

Physical resources are also important for researchers. Access to equipment, facilities, and academic publications are essential for understanding previous research and performing experiential research. Laboratories and scientific equipment are essential for researching and costs can be significant (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992; Lombardi, Capaldi, et al., 2005; Volkwein and Sweitzer, 2006; Mathies II, 2010). Capital expenditures for research equipment and facilities were identified as key components to research productivity in many of the studies discussed above (Ehrenberg, Rizzo, and Condie, 2003).

Library volumes and the Association of Library Index have been used in many studies assessing the quality of doctoral programs and academic research (Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992). In his report assessing doctoral research programs in 1966, Allen Cartter referred to libraries as the “heart” of a university. Subsequent studies included library holdings as a gauge of the quality of the institution (Cartter, 1966; Jones, Lindzey, et al., 1982; Ashton, 1984; Ashton and Leslie, 1986; Leslie and Brown, 1988; Groth, 1990; Groth, Brown, et al., 1992; Grunig, 1997; Mathies II, 2010). It wasn’t until Kendon

Stubbs, however, that a library index was developed that incorporated more than the total number of volumes (Roose and Andersen, 1970). Rushton and Meltzer (Stubbs, 1980) found a strong relationship between library books and journals and academic publications and citations.

Like library volumes, university endowment is another measure commonly used in assessments of the of the wealth and quality of an institution (Rushton and Meltzer, 1981). Endowments represent the resources available to an institution for future investments in research, students, commercialization, start-ups, or capital projects (Cartter, 1966; Ashton, 1984).

Thus, physical resources are expected to have a positive influence on research activities. The following observed variables were used to determine the latent variable of the Physical Resources Factor:

1. The average capital investment in the academic field of research between 2001 and 2005, measured as the total of capital expenditures for equipment and facilities in millions of dollars.
2. The University Library Index for 2005.
3. The value of the endowment of the university at the end of 2005 in millions of dollar.

The Data

The data used on departmental and institutional level resources comes from several sources, all available online. The first is from the National Science Foundation. There were 968 departments at 145 research universities that were represented in the survey. The NSF-IPEDS web site, Webcaspar,[21] provided data on the R&D expenditures, capital expenditures, and students and post doctoral researchers.

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[21] https://webcaspar.nsf.gov/

University Library Rankings were obtained from the Association of Research Libraries.[22] University endowments were obtained from the 2005 National Association of College and University Business Officers (NACUBO)[23] and from the annual report of the Chronicle of Higher Education.[24] Lastly, the National Research Council's most recent doctoral quality survey provided data on the number of faculty members, average publications per faculty member, average citations per faculty publication, and the percentage of faculty members with grants from 2005.[25]

One of the challenges in developing any measure is ensuring that all the appropriate data have been incorporated into the measure and there are not systemic omissions. Capturing the government expenditures for different departments requires discerning which expenditures are likely to be allocated to particularly departments, since the data are classified by discipline or academic field, rather than by department. The relevant fields were identified for each department and these expenditures were used. For example, for researchers in a Chemistry department, the "Chemistry" expenditures were used. For those in Nutrition and Food Science departments, "Agricultural Sciences" expenditures were used. For departments with multiple fields, the appropriate expenditures were combined. For example, for a Department of Earth and Planetary Sciences, expenditures for "Astronomy," "Atmospheric Sciences," and "Earth Sciences" were combined. Similar actions were taken to determine the number of graduate and doctoral students available in each department. While some inaccuracies may be inherent in this determination, the purpose is to identify the relative

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[22] http://www.arl.org/stats/annualsurveys/arlstats/index.shtml
[23] http://www.nacubo.org/documents/about/fy05nesinstitutionsbytotalassets.pdf
[24] http://chronicle.com/stats/endowments/
[25] http://www.nap.edu/rdp/

research resources for the departments that researchers work in, rather than to identify the specific resources used by each individual researcher.

Results

There are four possible methods that can be used for calculating factors: (1) Principal Factor; (2) Principal Component Factor; and (3) Iterated Factor. The difference between the methods is in how the correlation matrices are analyzed. Principal Factors uses the squared multiple correlations as the estimates of commonality. Principal Components Factor analyzes the correlation matrix assuming the communalities are 1. Iterated Factor Analysis estimates the communalities of the correlation matrix through iteration (Hansmann, 1990; Shane and Toby, 2002).

For the human resources and physical resources factors to be developed, all three methods were used to develop the factors. This allowed for analysis of consistency and evaluation of the best method for developing the factor, based on goodness-of-fit tests. Confirmatory factor analysis was then used to confirm the development of the factor.

Table A.1 shows the results from the factor analysis for the Human Resources Factor using the Principal Factors, Principal Components Factor, and Iterated Factor. The eigenvalue indicates the variance of the factor. In multiple factor analysis, the first factor developed will absorb the greatest amount of the variance. In this analysis, a single factor was theoretically conceptualized and thus, the factor analysis was constrained to develop a single factor. Analysis shows that the Human Resources Factor developed through principal factors uses 0.8818 of the total variance and has a Cronbach's alpha of 0.8014. Cronbach's alpha is a measure of the internal consistency of the factor and shows how well the observable variables used to develop the factor are related as a group (Stata Press, 2008, see specifically the entry on the "Factor" command). The human resource factor developed through principal factors was used in the models testing the effect of departmental research resources in Chapter 3.

Table A.1 Results from Human Resources Factor Analysis

Human Resource Factor	Eigenvalue	Proportion	KMO Measure	Cronbach's alpha
Principal Factors	1.69624	0.8818	0.6364	0.8014
Principal Component Factor	2.24276	0.4486	0.6364	0.8009
Iterated Factor	1.84449	1.0000	0.6364	0.6951

Confirmatory Factor analysis on the observable variable for the Human Resources Factor [HUMAN] showed that each of the observable variables used – number of faculty members, average publications per faculty member, average citations per publication, average number of PhD graduates, and average number of graduate students were all significant for the development of the factor. Analysis of the results showed that the factor developed through principal factor is the strongest factor. The factor accounts for 0.8818 of the variance and has a Cronbach's alpha of 0.8014.

For the physical resources factor, the five year total equipment expenditures for each department in millions of dollars, the Association of Research Library Index for the Institution, and the institutional endowment at the end of 2005 were used as indications of the underlying physical resources available to the researcher. The results of the factor analysis are presented in Table A.2.

The Cronbach's alpha for the physical resources factor was 0.7966, which is relatively low for an acceptable factor, but will still allow the factor to be used. The factor developed through Iterated Principal Component Factor Analysis was used in the analysis.

Table A.2 Results from Physical Resources Factor Analysis

Physical Resource Factor	Eigenvalue	Proportion	KMO Measure	Cronbach's alpha
Principal Factor	0. 42345	2.3298	0.5545	0.7525
Principal Component Factor	1.35573	0.4519	0.5545	0.7364
Iterated Factor	0.58737	1.0000	0.5545	0.7966