STUDENT CENTRALITY IN UNIVERSITY-INDUSTRY INTERACTIONS

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LIST OF ABBREVIATIONS

AUTM	Association of University Technology Managers
CV	Curriculum Vitae
ERC	Engineering Research Center
FTEs	Full Time Employees
HBCU	Historically Black College and University
HLM	Hierarchical Linear Modeling
I/UCRC	Industry/University Cooperative Research Center
ISI	Institute for Scientific Information
NCES	National Center for Education Statistics
NSF	National Science Foundation
OLS	Ordinary Least Squares
R&D	Research and Development
RVM	Research Value Mapping
S&E	Science and Engineering
STC	Science and Technology Center
STHC	Scientific and Technical Human Capital
TTO	Technology Transfer Office
UIRs	University-Industry Relationships
USPTO	United States Patents and Trademarks Office

SUMMARY

This thesis proposes and estimates a model of university scientists' interactions with the private sector; in this model students are conceptualized as an important enabler of such interactions. The results of the study show that university scientists' student-related behaviors such as grant support of students and research collaboration with students, and student-related attitudes such as mentoring orientation positively affect the probability that scientists will enter interactions with industry as well as the intensity of such interactions. Behaviors such as teaching and advising of students are not related to interactions with industry.

This study is motivated by the increased emphasis on closer relationships between universities and industry as a means to facilitate the commercial application of university research. Today, numerous policies and programs attempt to achieve such goals. As a result, university scientists are called on to perform many tasks which on the surface seem misaligned. There is substantial study of conflict between the teaching and research missions of universities, and a growing body of study on conflict related to university based commercial and technology transfer related activities. Fewer, there are studies suggesting that these activities are not so misaligned after all. This study falls into the latter category as it posits a complementary relationship between university scientists' student related activities and their work related interactions with industry, research and otherwise.

Speculations regarding the importance of students in university industry relations and indirect evidence are scattered through the relevant literature, but little or no systematic empirical tests of their importance exist. This study uses data from a national survey of university researchers to discern the centrality of students to university-industry interactions. Theoretically, students are conceptualized as a dimension of university scientists' respective research capacities that enable cross-sectoral processes of accumulative advantage and thereby help to enable their interactions with industry. As a component of scientists' scientific and technical human capital, students help university scientists to identify and act upon on research opportunities originating in the private sector. Moreover, students increase the appeal of university scientists to industry agents seeking research partners in academe. Implications for theory and policy are discussed.

1. INTRODUCTION

Relationships between universities and industry have been extensively, but rather haphazardly researched. Interest has focused largely on the formal arrangements between the two establishments, which aim to foster and institutionalize the production of commercially relevant knowledge (Etzkowitz, Webster, & Healey, 1998). These arrangements usually concentrate on the flow of such knowledge "deliverables", most commonly in the form of patents or licenses (Agrawal, 2001). While the popularity of such arrangements between universities and their industry partners is not surprising, especially given their relative novelty and policy visibility (OECD, 2002), overemphasizing such mechanisms does not do justice to equally if not more important, albeit indirect, linkages between academia and industry.

The focus of this study is a major yet understudied component of university-industry relations: students. What little attention has been given to the role of students in industry-university relations (e.g., Croissant & Restivo, 2001; Slaughter, Campbell, Holleman, & Morgan, 2002) has chiefly examined the impact of the industrial activities of the of universities and university scientists upon students. But is it possible that students' interaction with industry ultimately affects the research and industrial activities of the faculty with whom the students are working? This thesis suggests that students may be important, active, component of university-industry interactions at the individual level by enhancing university scientists' capacity to enter and succeed in such interactions.

Why might one expect this? In the first place, there is the intuitive expectation that influence patterns are rarely unidirectional. More important, research (e.g., Roessner, Ailes, Feller, & Parker, 1998) has demonstrated the key role of students (access to students, recruitment of students, and student internships and cooperative programs) in industrial firms' strategic choices in university collaboration. Since students are now recognized as a prized resource in university-industry collaboration, it is possible that students' industrial activities will affect not only industrial clients and sponsors, but the university faculty mentors and co-researchers as well. Hence, the goal of this study is to describe the effect of university researchers' interactions with their students on the likelihood that these researchers will enter into collaborative relationships with the private sector.

The goal of this research then is to assess the relationship between university-based scientists and their students, and the impact of that relationship on these scientists' interactions with private sector companies. Framing the question in such a way allows this research to directly address the broader theoretical proposal of this thesis, namely that interactions with students may be an important explanatory factor in modeling university-industry interactions at the individual level. The current study thus provides a methodological opportunity to bridge the "interaction" and "interdependence" theories of academia-industry relations (Geisler, 1995).

University-based scientists who interact with industry, both formally and informally, recruit students to work on industry-funded projects, collaborate with students on problems of possible industrial interest, as well as consider both the contributions their students could make to solving industrial problems and the training value of such problems for the students they mentor. Scientists also assist in the placement of students in internships and work cooperative programs, and they mentor students regarding their lives after graduation, providing advice on career choices in both industry and academia.

By engaging in such student-related activities scientists not only perform a task typically expected by most scientists, but also accumulate experiences and research capacity that over time may make them both more able to pursue and act upon industrial opportunities and more attractive research partners for private companies. Indeed, from the perspective of private companies, the role of university academics in leading them to new recruits is one of the most important aspects of their interaction. The students organizations hire after graduating have often worked with the company in some capacity through their academic mentor, either informally or as an intern (Feller & Roessner, 1995). The student-related benefits for private companies are not “on hold” until students graduate and get possibly hired by these companies. On the contrary, gains for companies interacting with university scientists are often immediate as they work with students on tasks requiring the high level expertise possessed by advanced degree students, but not provided by the scientist himself: testing, prototyping, software writing, experimentation. In the process of such interactions companies may often receive on-going technical assistance and problem solving from the students, not the faculty responsible for the interaction. In such environment of collaborative effort then, students are not merely passive participants, but likely an important, necessary component of such interactions.

The role of students in the relationships between university scientists and industry players is therefore of key importance, because these students do not remain students, but become professional scientists and engineers who work in industry, academia, or both.

Students thus constitute a key component of university-industry relationships insofar as all three entities (faculty, students and organizations) interact in a variety of processes such as exploratory research of mutual interest, training and technical assistance, and also in the process of matching graduates with advanced degrees to industrial firms in need of new employees with such specialized skills.

Framing students as an active component in the interactions between firms and universities will help both to 1) better explain why and under what circumstances some university researchers interact with the private sector (while their colleagues of similar background and credentials do not), and to 2) assess the dynamics of the relationships between universities and firms. The better explanation of why some scientists are more likely to interact with the private sector is sought through conceptualizing students as an asset particularly relevant and valued by industrial partners. As a result, scientists who are more involved with students in various capacities are likely to be dispropoortionally more able to enter and sustain interactions with industry relative to colleagues less engaged with students. This is essentially a situation where particular dimension of the scientific role is likely to receive disproportionally higher rewards relative to other dimensions. In the context of interactions with private sector, involvement with students may be rewarded (in terms of recognition, collaboration and funding opportunities) higher relative to rewards associated with this dimension in other contexts (e.g. in the context of traditional academic departments).

The problem of inequal distribution of scientific assets and outputs and the differential returns on such assets and outputs has been previously conceptualized as "accumulative advantage" (Merton, 1968), reinforcement, or both (Fox, 1983). Such theories hint at the possibility that, and provide heuristics to assess situations in which different aspects of "doing science" may gain or lose centrality and maybe associated with more or less rewards. Previous research at the institutional level has shown that processes of accumulative advantage occur not only within, but also across the academic and industrial sectors (Owen-Smith, 2003). If this process holds at the individual level as well – as this thesis implies – then the scientists more likely to interact with the private sector will be the ones that have overdeveloped one particular dimension of their research capacity, namely the students with whom they collaborate, support through grants, teach and advice. This thesis considers the possibility that involvement with students, too, may be unequally disctibuted across scientists and that rewards on such involvement – in terms of interactions with industry - may vary accordingly.

A Brief Overview of Past Research

The theoretical and empirical background for the current research is presented in detail in Chapters 2 and 3. In essence, this research has examined different types of arrangements, the effects (benefits and downfalls) of such arrangements for both firms and universities, and the role of individual faculty members in promoting such relationships. Previous theories of complementarity and accumulative advantage will be particularly discussed, given that the mechanisms they conceptualize partially inform the reasoning underlying the current research. The major findings of this past research will now be briefly summarized to provide a basis for presenting in detail the goals, theory, specific research questions and contributions of the current research.

Types of Arrangements

In sum, this research deals with the role of students in the context of university-industry interactions at the individual level. In this context, students may play multiple roles and be embedded in variety of mechanisms. One such mechanism is that university-industry interactions may provide direct inputs not only in terms of knowledge products, but also in terms of human capital. If so, such university-industry interactions may be de-facto important channels through which students become coupled with private firms. Crucially, this is not an isolated market labor process, but one interrelated with university-industry interactions. No doubt, interactions between firms and universities vary considerably in form. In some cases, these arrangements follow closely to the "linear model", in which a discovery by a university researcher is recognized by a business, which in turn collaborates with that scientist to exploit the finding (Pavitt, 2006). A different potential scenario is one in which a firm contracts with a university researcher to execute a particular type of research (Poyago-Theotoky, Beath, & Siegel, 2002). Another arrangement, perhaps currently the most common, is a blend between these two types of interactions. This relationship begins when the university research is still in embryonic stage, and additional work is then undertaken through collaboration between the researcher and industry, in which both parties engage in "experimentation" with the rudimentary results and explore their respective interests (Poyago-Theotoky, Beath, & Siegel, 2002). In this case much additional exploratory work needs to be done before commercial application or development even come to the agenda (Randazzese, 1996). This type of experimentation involves the sustained cooperation of the university scientist, and especially of graduate students , often involving students trained by the original researcher (Randazzese, 1996).

Effect on Universities

Some observers argue that universities in the United States have always maintained close ties with local industries and state economic development missions, and hence suggest that university-based applied research is not a new phenomenon (Crow & Tucker, 1999; David Mowery, 2001). No matter' one's take on the issue, there does seem to be a growing trend towards encouraging more commercially relevant research in universities as evidenced by the focus of the technology transfer legislation in the last two decades, as well as the growth of patenting, licensing and funding from industrial sources on US university campuses. How does this intensified collaboration interact with the primary role of universities, the training of skilled professionals? Is this function beginning to be neglected for the sake of alliances with industry? One answer to these questions simply states that industry and academia have always been intertwined, given that the most important method by which universities aid industry is by educating students, thereby increasing the scientific and engineering capacity of the labor pool from which industry selects its workforce (Leydesdorff & Etzkowitz, 1998; Williams, 1986). In this sense, universities and industry have been "interactive" for much longer than studies of boundary spanning arrangements and technology transfer presume.

However, one result of over-emphasizing the recent growth of university-industry (boundary-spanning) arrangements is that evaluations of the effects of such arrangements tend to focus on concrete outcomes for one party or the other. In other words, the dynamics of the interaction is often reduced to discrete outputs and business gains of the industry, or the costs and benefits for the university (Behrens & Gray, 2001). Less is known about the more subtle processes that may take place when universities are under pressure to accommodate more commercially relevant research as a part of their normal operations (e.g. in the everyday research lives of faculty), over and beyond the highly visible but limited in scale and scope arrangements such as research centers and university patenting and licensing.

Are university researchers subject to conflicting demands or do they successfully integrate core academic functions such as student mentoring with newer roles initiated by the private sector? One approach to addressing this issue dichotomizes the worlds of academia and industry, and consequently discusses cross-sector collaboration in terms of "clash of cultures", or conflicts of interest (Bray, 1990; Campbell, 1997; Campbell & Slaughter, 1999; Geiger, 1988; Hendee, 1990; Johns, Barnes, & Florencio, 2003; Korenman, 1993). The impact of such tensions on various aspects of universities has been widely studied. These include investigations of student identities (Gluck, Blumenthal, & Stoto, 1987; Hackett, Croissant, & Schneider, 1992), concerns over intellectual property (Blumenthal, Campbell, Anderson, Causino, & Louis, 1997; Kleinman & Kloppenburg, 1988; Newberg & Dunn, 2002), implications of academic entrepreneurship (Karen Seashore Louis, Blumenthal, Gluck, & Stoto, 1989; Murray, 2004; Stephan & Levin, 1996), researchers' attitudes to commercial involvement (Bogler, 1994; Etzkowitz, 1998; Glaser & Bero, 2005; Y. S. Lee, 1996; Owen-Smith & Powell, 2004), benefits for business and universities (Blumenthal, Causino, Campbell, & Louis, 1996; Fairweather, 1995), and the possible interference of industry in the research agenda of universities (Webster, 1994)[1].

Role of Individual Researchers

There is a growing consensus among academics and administrators that university-industry collaborations allow for multiple routes to academic commercialization. Individual university faculty members also vary in their response to increased academic commercialization, and these choices, "have created a myriad of positions that are neither old nor new school, but instead combine characteristics of both" (Owen-Smith & Powell, 2004). Adjustments[2] of work practices in response to increased industry involvement are more likely to be incremental than revolutionary. Incremental changes to individual and institutional behaviors in response to academic commercialization include diverse behaviors that form strong (and unpredictable) interdependencies, resulting in a tightly coupled system susceptible to generating unexpected consequences (L. Nelson, 1998). Individual university staff members play a formative, as well as a reactive role in such relationships between researcher and organization. Hence the behaviors of faculty members must be conceptualized not only as a by-product of academia-industry relations, but also as instruments of proactive adjustment, an autonomous driver or "shaper" of university-industry interactions.

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[1] Past research has focused largely on disciplines such as the life sciences, medical research and biotechnology. This is not surprising considering that these fields account for most of the commercial involvement in universities. However, university-industry interactions incorporate many different disciplines.

[2] Note that this discussion does not condone the normative implications of the term "adjustments", which would imply that university practices are static and are molded by the external environment. In contrast, academia is an active participant in these relationships.

Effect on Industry

Within academia-industry interactions, firms appear to recognize the importance of acquiring trained researchers familiar with the latest research techniques, even if no direct transfer of technology takes place. In fact, the provision of such individuals is often ranked by firms as the greatest benefit provided by universities (Martin & Salter, 1996). This holds true even if a particular discipline as such has few direct industry applications (Pavitt, 2006). Thus for private organizations, interaction with universities is seen a means of acquiring trained professionals to sustain and expand their innovative activities.

Existing studies support such reasoning by finding that companies typically value generic research skills in the new graduates, rather than the academic expertise in a particular field (Richard R. Nelson, 1987). “Industrial scientists and engineers almost always need training in the basic scientific principles and research techniques of their field, and providing this training is a central function of universities. Current academic research in a field, however, may or may not be relevant to technical advance in industry, even if academic training is important” (R. R. Nelson & Levin, 1986). Similarly, some critics of applied research in universities argue that the fundamentals of research are an integral part of student training. “The final, and most important justification for public subsidy is training in research skills, since private firms cannot fully benefit from providing it when researchers, once trained, can and do move elsewhere” (Pavitt, 1991). Usually firms cooperate with universities in the acquisition of skills and knowledge (Feller, Ailes, & Roessner, 2002), suggesting that they value not only specific research findings, but also access to the knowledge embodied in the students with whom they interact.

Other studies have examined arrangements between universities and organizations which explicitly attempt to reduce the boundaries between academic and industrial research. Even in this context, access to skilled graduate students is among the chief benefits private companies realize (Feller, Ailes, & Roessner, 2002; Roessner, Ailes, Feller, & Parker, 1998; Slaughter, Campbell, Holleman, & Morgan, 2002). Some firms even pursue long-term collaborations with the universities specifically to create “extended internal labor markets” for recruitment of graduates and scientists (Feller & Roessner, 1995; Lam, 2005).

Previous Theories

One could not fail to notice that previous studies, some of which discussed above, have not formally examined the role of students in the interaction between academia and industry at the individual level. They instead find and report the reported importance of student interactions for firms (Feller & Roessner, 1995; Roessner, Ailes, Feller, & Parker, 1998), for university faculty (Slaughter, Campbell, Holleman, & Morgan, 2002), or discuss the issue in terms of the perceived effect on students (Behrens & Gray, 2001) (e.g., Behrens & Gray, 2001). Very few studies assess the role of students in the relationship between academics and industry. One notable exception, to be discussed later, is the work of Slaughter and colleagues (Slaughter, Campbell, Holleman, & Morgan, 2002).

As stated above, the current research seeks to investigate the role of students as a possible important factor facilitating or even driving such collaborations, in an attempt to discover whether this factor can explain why some university scientists are more likely to interact with the private sector than are others. Currently this behavior is often attributed to individual scientists' productivity (Blumenthal, Gluck, Louis, Stoto, & Wise, 1986). Such attribution is plausible but also misleading because by focusing on single aspect of scientific "ability" one cannot discern what particular endowments or capabilities facilitate interactions with industry because all such variables are probably strongly associated with productivity yet may have different relative importance. Identifying patterns of student-scientist behavior – one of the most important and traditional role of scientists besides their role of producers of research publications – may enable the isolation of drivers of certain types of university-industry interaction. This research may thus also reveal drivers of certain goals regarding student mentoring, teaching and collaboration.

The established linkage between productivity and industry interactions however provides an important hint: evaluating the nature of the links between "core academic" and "industrially relevant" behaviors may be better accomplished by models postulating complementarity and possible reinforcement, rather than those emphasizing independence, "clash of cultures" and otherwise lurking conflict. This thesis adopts the former, albeit less common approach, by exploring whether the student-related behaviors displayed by some academics may be conducive to industrial interactions. The current research thus tests a model which uses the concept of complementarity between faculty, students and private industry.

The model assessed in the current research is partially informed by a peculiar phenomenon found in science and its conceptualizations. The phenomenon that provides a gateway into the possible conceptualization of students as assets in university-industry interactions is the "skewness" of the distribution of scientific inputs, most visible in the distribution of publications (David, 1994). For reasons that are still poorly understood (in part of the great difficulty of measuring the phenomenon and acquiring the necessary data), scientists who manage to initially accumulate certain assets or outputs continue do so at disproportionally higher rates than scientists who did not yet make their mark. The theory of accumulative advantage shows similar mechanism in the case of recognition (Merton, 1968). This theory states that scientists who already possess significant reputational and research-capacity resources will receive disproportionally higher returns on such assets, relative to scientists or institutions in more disadvantaged position. Recently, Owen-Smith (2003) revealed that the phenomenon of accumulative advantage takes place not only within sectors (e.g. industry vs. academia), but also across sectors (e.g., universities who are more successful in producing high impact basic research tend to also be more successful in producing commercially relevant outcomes). He also provides evidence that this trend may hold at the individual level, and postulates a continuous interaction between faculty behaviors and industrial involvement (Owen-Smith & Powell, 2004). In other words, interacting with industry is not something that suddenly alters the mindset of individual faculty members, but rather that individual researchers reevaluate their behaviors and strategies in the process of interacting with the private sector.

While the current thesis does not attempt to apply the theory of accumulative advantage to the case of student involvement, this theory provides insight that allows conceptualizing the mechanisms through which over-developing certain aspects of the scientific role may result in certain rewards and advantages. Whether such advantages are "accumulative" is irrelevant for the current research. What is important for the current conceptualization however is that investment in student interactions by university scientists may result indeed in certain “advantages” such as facilitated interactions with the private sector.

The Current Research

The reasoning put forward in this thesis conceptualizes students as an active component in the interactions between firms and universities. This thesis extends previous theories by claiming that interactions between industry and university students are a strong driver of university-industry interactions, not merely a convenient by-product. This reasoning leads to the general hypothesis of this work which is that more intensive interactions with students lead to more intensive interactions with the private sectors. For example, interactions with students signal, among other things, engagement by university scientists in research with potential commercial applications. Such student-faculty interactions are thus hypothesized to increase the capability and attractiveness (from the standpoint of industry), of university scientists for collaborative interactions with industry.

In this proposed reasoning university students are conceived as central to researchers’ capacity to identify, act upon, and exploit interactions with industry. As a result, scientists who are more involved with students in various capacities are likely to be more able to enter and sustain interactions with industry (relative to colleagues less engaged with students). This mechanism can be interpreted as an enhancement of particular dimension of scientists’ scientific and technical human capital (Bozeman, Dietz, & Gaughan, 2001) and interactions with the private sector provide higher returns to developing such capacity. This may or may not be an accumulative process, however this is of peripheral interest here. What is important to test however is whether such investments in student-related behaviors will indeed result in more intensive industrial interactions.

Previous research at the institutional level has shown that excelling in traditional roles of universities such as high quality basic research enhances their ability to succeed in commercially relevant activities (Owen-Smith, 2003). The current theory proposes that this process should hold at the individual level, suggesting that scientists are more likely to interact with the private sector if they have overdeveloped one particular dimension of their research capacity, namely supporting and collaborating with students. This thesis empirically assesses whether excelling in one of the dimensions of the traditional scientific role – interactions with students – also facilitates excelling in interactions with industry. This conceptualization postulates that involvement with students represents a dimension of scientists' research capacity that is particularly well suited to facilitate interactions with industry. From this basis it can be predicted that the presence of "more" of this research capacity places the scientist in a position to enter collaborative relationships with industry more often than scientists who are less involved with students. In other words, those members of the faculty who invest more in student relationships have both "more to offer" to industry (e.g., a pool of labor to allocate to projects of interest to industry, possible future employees), as well as "more to get" from industry (e.g., a capability to explore and act upon research "leads" from industry that are labor intensive and would require sufficient expertise to explore, but at low cost).

The current research seeks to assess whether university scientists' involvement with students (e.g., grant support, collaboration, teaching) influences the nature of these scientists' future relations with private sector companies. The findings should contribute to an explanation of why and under what circumstances some university researchers interact with the private sector, while their colleagues of similar backgrounds and credentials do not. A second purpose of this thesis is to assess the dynamics of the relationships between universities and firms. This should allow practical application of this research to the improvement of academia-industry relations.

Research questions

The overarching research problem addressed in this thesis is whether or not university scientists' relations with students stimulate these scientists' interactions with the private sector. More specific research questions generated by this are as follows.

1) How does grant support of students relate to interactions with industry? Is supporting more students through grants associated with a higher probability of entering industry collaboration? With higher intensity of industry interactions? Is it particularly strongly associated with some versus other specific types of industry collaboration?

2) How does research collaboration with students relate to interactions with industry? Is research collaborations with students associated with a higher probability of entering industry collaboration? With higher intensity of industry interaction? Is it particularly strongly associated with some versus other specific types of industry collaboration?

3) How is teaching related to interactions with industry? Is spending more time on teaching, as a particular form of student involvement, also associated with a higher probability of entering industry collaboration? With higher intensity of industry interaction? Is it particularly strongly associated with some versus other specific types of industry collaboration? Or is there a tradeoff between teaching and interactions with the

private sector - do scientists try to minimize their teaching involvement in order to pursue industrial collaborations?

4) How is interest in mentoring students related to interactions with industry? Does more interest in mentoring mean more aptitude in cultivating resources of interest to industry and thus lead to a higher probability of entering industry collaboration? Is it also associated with higher intensity of industry interaction? Is it particularly strongly associated with some versus other specific types of industry collaboration?

5) How is advising of students related to interactions with the private sector? Are scientists who invest more effort in advising students also more likely to be more involved in private sector interactions? Are they more likely to interact with the private sector more intensively? Are they more likely to enter some versus other types of industry interactions?

The effects of these types of scientist-student involvement are examined across a spectrum of industry-related behaviors.

The contributions of the study

The importance of the current research lies in uncovering the interrelations between researcher-student relationships and collaboration between the researcher and the private sector. The research questions are designed to investigate whether interactions with industry are becoming an integral, complementary part of core activities (such as training of students) or whether there is a trade-off between the core and industry-related activities of university scientists. Crucially, this research will demonstrate how two behaviors typically considered as antithetical may in fact reinforce one another. In other words, how everyday academic activities such as teaching and student mentoring may in fact enhance certain types of interactions with industry. In doing so, this study will both inform some current policy debates regarding the desirability and feasibility of increased interactions with industry of US universities and will also contribute to the understanding of the factors that facilitate and drive such relationships.

The conceptualization advanced and tested in this thesis suggests that student-related behaviors of faculty are an important asset that in fact enhances scientists' capacity to interact with the private sector, but are not a load that scientists "shed" in order to be able to pursue industrial opportunities. The results from testing this conceptualization have implications both for policy and theory.

By addressing these questions this thesis will provide a better explanation of university-industry interactions at the individual level, in which the role of students may be one of a key component or a driver. In answering such questions, this research will also contribute to understanding the mechanisms through which university-industry interaction occurs at the individual level. Studying the role of student interaction within this context will also provide insights into the ways in which firms realize the benefits embodied in students. That is, this research will also indirectly aid understanding of the way in which graduate students can be direct inputs into firms' innovative capabilities.

By identifying the complementarities between a core function (e.g., teaching and mentoring) and a desired function (increased relations with industry) this research will contribute to the better understanding of interactions between individual faculty members and the private sector. The dominant explanation for the pattern of university-industry interactions (as mentioned above) is productivity. The current research proposal suggests that simplifying the issue down to productivity may minimize the effect of particular endowments, characteristics and behaviors of university scientists that increase the likelihood and intensity of their collaborations with industry. In particular, involvement with students while a traditional role of university scientist, has been under-emphasized in the academic rewards system. In today's context of increasing competition for industrial funds and forging closer linkages with industry, this dimension of scientists' roles may enable them to be better positioned to claim and utilize the rewards resulting from industrial interaction. More importantly, this thesis suggests one particular mechanism through which university scientists' competencies get utilize by the private sector. While scholarly ability as measured through publications is always important, it does not provide explanation of how and why interactions with industry occur. Involvement with students may be one such particular mechanism through which scientists enable interactions with the private sector.

The findings will thus have ramifications for policy makers, and university administrators and those interested in technology transfer and economic development.

2. RELATED STUDIES

Although very few studies have pursued specifically the problem of interest in this proposal – the implications of faculty relationships with students for the interactions of these faculty with industry – a larger family of studies, taken up in accord, contains the necessary propositions that can be weaved into a conceptualization of faculty-industry interactions explicitly accounting for the role of students in these interactions.

The purpose of this review is not simply to summarize different studies having varying degrees of relevance to the research topic of this thesis, but 1) to demonstrate that the questions considered in this work have been partially, at least in passing, considered or implied in almost all branches of the science and technology policy literature, that 2) in such studies this consideration however is partial or not of primary interest and 3) that synthesis of the relevant propositions scattered through this literature can serve as a basis of a model giving explicit and systematic consideration of the role of students in the university-industry interactions at the individual level. As a result, the sections of the review below are accompanied by my own commentary pointing up deficiencies concerning the conceptualization of students. These commentaries I then summarize at the end of the chapter in a "meta-model" in which I position and formalize the hypotheses concerning the relationships between student- and industry-related faculty behaviors. Therefore at the conclusion of this chapter my task shifts from review of the extant literature to the (albeit selective) synthesis thereof.

Students as an input in private sector innovation

Policy efforts to enhance university-industry interactions have focused mostly on making it easier for private companies to access and appropriate the pools of scientific knowledge produced in universities, while this knowledge is typically perceived in the form of "deliverables" to be produced and offered to industry. However, research is only one of the industrially relevant missions of the universities, and not the oldest one. The educational mission of universities is comprised by the recognition of talent, training and research (Schultz, 1976), with the more recent addition of economic development mission.

The important government objective to provide public education aside, justification of publicly supported training for students is quite similar to the justification of supporting public R&D. Private firms need trained employees to perform their day-to-day as well as innovative activities. Some of these activities demand firm-specific knowledge (acquired on-the-job), but most of them demand generic skills[3] that are applicable in multiple settings. In such a case, in spite of the benefits associated with having educated employees possessing such generic skills, most firms would have disincentives to provide costly training for employees who may then "take" the new skills embodied in them and transfer to another organization - hence the term "transferable skills" (Becker, 1975). Becker's conclusions was that workers, not firms receive the complete returns on general skills (Becker, 1975). The implications of this conclusion are that 1) workers should (and will) bear the costs of acquiring such general, or transferable,

[3] "Generic" in no way is synonymous with lower level or "basic" skills. Some generic skills, such as mastery of certain scientific and engineering principles, deep knowledge of specific technological area, can be extremely sophisticated.

skills (i.e. they will invest in their human capital) and 2) firms will underinvest in general training (because of their inability to capture the full returns on it).

While the first implication above concerns mostly individuals' decisions regarding the investment in their human capital (e.g. through tuition and foregone salary while receiving education), the second concerns the major role of the universities as providers of such general training thus correcting for the market failure resulting from limited appropriability of returns on generic skills by firms. Becker did not consider the underinvestment in general skills to be a problem: neither conceptually (he implied that firms don't need much general skills anyway) nor practically (several decades ago, when his work was published, the "knowledge inputs" in the economy were of lesser importance relative to nowadays). Subsequent research however has shown that firms do, in fact, invest in general training (Stevens, 1994), and more importantly – that the knowledge, skills and problem-solving capacity embodied in the new university graduates firms employ may be of much greater importance than any specific expertise in particular field (R. R. Nelson & Levin, 1986). The "active fusion" (Tomlison & Milaes, 1999) between the knowledge brought by the worker and the one generated within the firm enhances both the worker's human capital and leads to modification of firm's capabilities thus enhancing its innovative capabilities (Tomlison & Milaes, 1999).

As innovative activities in business firms have become more professionalized (and university research more specialized), universities now play more important role in providing the trained researchers for firms to perform their innovative activities (Pavitt, 2006). The increasing importance of advanced scientific problem-solving skills combined with the possible underinvestment in such type of training helps to elucidate the importance of graduate education in the context of university-industry relations and private sector innovation. While firm specific knowledge of certain processes and technologies is a prerequisite for maintaining employment in an organization, in the contemporary knowledge intensive economies, the capability of employees to acquire the firm specific knowledge at the first place, and then contribute to the development of firm's knowledge capacity, is dependent on a system of a science and engineering education that prepares graduates for careers in industrial firms by equipping them with training in scientific principles and tools. The more advanced the knowledge of an employee, the greater his or her ability to meaningfully utilize external sources of information to use in in-firm innovations (Gibbons & Johnston, 1974).

This means that there is a long way before individuals are molded into employees who can actually contribute to knowledge intensive industrial innovation. This process is largely borne by the higher education system. The future private employees need first to be recognized as possessing the minimum levels of "talent" to perform in knowledge occupations (and the ones who lack ability or motivation are filtered out), and then trained in the set of generic science skills that would make them capable of adapting to the requirements of the industrial firm.

Universities, as part of their mission bear the considerable costs of this pre-processing of the human resources used by firms. In doing so they contribute to solving serious and costly problems for private firms, namely 1) the lengthy and uncertain search process of identifying eligible employees – by recognizing "talent" (Schultz, 1976) and 2) by providing this narrowed pool of eligible employees with the appropriate training and stamping them with the "stamp of approval" of the educational system (the university diplomas) certifying their minimally acceptable mastery of a set of standardized knowledge.

New scientific knowledge, albeit published, is not truly freely available to companies until is has been incorporated in the educational curriculum (Gibbons & Johnston, 1974). Therefore, the importance of the continuous stream of students is not simply in the assurance provided by the university system that they meet the minimum standards, but also that every next cohort of students arguably possesses more advanced and up to date knowledge than the previous one. Secondly, and more important in the context of "real time" UIRs and graduate education, interactions with university faculty and their students gives firms an opportunity to access the new knowledge embodied in students even before it is published, and much earlier than this new knowledge could be, perhaps, incorporated in the educational curriculum.

The possession of a university diploma certifies that an individual is equipped with the minimum capacity to develop firm-specific knowledge. The diploma is a formal credential, which, advertised on the labor market by the recent university graduate looking for paid employment, arguably leads to a successful match with a firm in need of the knowledge resources embodied in this graduate. However, considering how broad is the contemporary higher education (at the undergraduate level) and considering how diverse the knowledge needs of companies, this process of "matching" on the labor market implies a tradeoff between breadth of the higher education and ability to contribute to sophisticated private sector innovation (which implies depth of knowledge). The possession of an undergraduate diploma is, in most cases, a ticket to an entry level position in a company, where the new employees are subject to considerable on-the-job training before they reach levels of experience allowing them to contribute to innovating processes within the firm.

Knowledge intensive companies, on the other hand, have labor needs not easily satisfied by entry level diploma holders. For example, prestigious industrial laboratories and small startup companies alike, need employees with advanced training, possessing considerably larger pools of knowledge and insight into their respective fields, mastery of particular technological areas, or a portfolio of advanced research skills typically not found in undergraduates. Such employees are generally produced by the system of post-graduate education (at the master's and doctoral level). Since the more advanced the educational degree, the more specialized the knowledge becomes, it may be argued, that it is increasingly more difficult to "match" graduates possessing very specialized knowledge in certain area, with equally small set of firms specializing in similar area (for example, consider an undergraduate with degree in aerospace engineering capable of finding employment in almost any engineering design or manufacturing business, such as the automobile industry, aerospace, civil engineering etc. versus a PhD level expert in energetic materials for whom only 2-3 possible employment options may exist that correspond to his level of education and capable of meaningfully utilizing his specialty).

For the purposes of this thesis, I speculate that one of the key aspects of university-industry relationships involves the process of matching graduates with advanced degrees to industrial firms in which they find employment. I do not argue that this is the dominant mode through which labor markets for graduates with advanced degree operate, however I do assert that the extent to which graduate placements are a result of university-industry relationships is not a by-product of such relationships, but may be an integral component of such interactions and may be expected by both sides in the interaction and may even drive certain types of university-industry interactions. Thus education is a more deliberate input in private sector innovation than is usually suggested. Moreover, since the work of students in the context of such interactions is a major part of their training, it can be argued that students in university-industry interactions are given the opportunity to both be identified by prospective employers and to acquire the skills demanded by such prospective employers in a context of a research partnership between their institution, scientific advisor, and a private company. As a result, university-industry relationships, besides accomplishing certain research goals, also assist in the process "scanning for and identification of talent" – something in which both the professors and the companies are interested.

Albeit it is widely acknowledged that the educational mission of the universities is crucial for supplying the economy with the human resources needed by the private firms to innovate, it is much less acknowledged that the processes through which the matching of university graduates (with advanced degrees) and industry needs occurs is not necessarily on a commodified market on which graduates find companies (or vice versa) and the market clears quickly. This scenario is fairly unrealistic. While, of course, it is possible and desirable to follow demand and supply of scientists and engineers at the aggregate level (such studies are considered in the next section), this type of analysis says nothing about the mechanisms through which eligible scientists actually get coupled with private companies – not an unimportant problem considering that the successful match is costly and becomes increasingly more difficult as the degree of specialization and sophistication of the knowledge in question increases. At the same time, finding such advanced scientists to work on innovative activities in firms is increasingly more important for high technology companies since they need such employees who can quickly identify and assemble the knowledge necessary for the firm to sustain its innovative products.

It may be the case that university-industry interactions solve market failures not only in regard to the type of knowledge produced, but also in regard to identifying and training to mutual benefit, the students that both universities and private firms need to sustain their research activities. Thus I speculate that students might be not only a resource input used in accomplishing university industry interactions, but even a driver of such interactions, on par with other goals of such interactions. This is one of the key contributions of this study.

The importance of S&T workforce for the national innovation system is widely recognized. Such studies, based predominantly on conventional S&E indicators, and sometimes on survey data, are concerned predominantly with monitoring training, occupational, supply and demand trends in scientific, engineering, technical and mathematical fields at the national, sector, or industry level (Beltramo, Paul, & Perret, 2001; Fox & Stephan, 2001).

S&T workforce issues

A set of works have examined the extent universities fulfill their function to provide quality workforce for industry. Romer (2000) complains that while the public policy in US has went great lengths to encourage the private sector utilization of science and particularly the demand for scientists and engineers with advanced degrees, it has done little to ensure that the educational system encourages the supply response necessary to satisfy this demand (Romer, 2000). He asserts that the educational system has failed to meet this demand not only in terms of "raw numbers" (at the undergraduate level - a claim also supported by de Grip & Willems, 2003), but also because the dominant forms of training and support of graduate students (especially PhDs) are geared exclusively towards academic employment in research universities – an institutional training context that "glorifies the academic career ad the expense of other scientific career paths" (Gaughan & Robin, 2004). Thus, considering that the production of PhDs has been growing through the 1990s, and that the dominant support mechanisms are the research assistantships, the outcome is increased supply of PhDs ("produced as a side effects of basic research" – Romer, 2002, p. 24) trained for research academic jobs at a time when the job prospects of getting such positions mostly decline (Romer, 2000).

According to Romer, the increase of non-faculty appointments happened not because of the raw increase in the number of PhDs, but in spite of the narrow research oriented training they received, and is also partially accounted for by sharp increase in post-doctoral positions, as well as by increased preferences among graduate students for non-academic careers combined with perceptions of bleak future in academia and improving prospects in industry (Fox & Stephan, 2001). The same study also mentions that it might be the case that there is oversupply of graduates, since university scientists have strong incentives to recruit graduate students and post-docs to work in their labs, but little incentive to mentor and educate them (Fox & Stephan, 2001). Ehrenberg (1991) identifies that the propensity of recent PhDs to work increasingly for industry is in part a response to higher relative salaries in industry and also related to the types of academic jobs available. Most students enter graduate school with the expectation of working in the academic sector, but desire such positions mostly in the research 1 universities and substantially less so in 4 year institutions. Considering that such top research jobs are scarce, industry becomes more appealing (Stephan, 1996).

Among the variables considered in explaining early career outcomes of Ph.D. graduates, studies have shown mixed effects of having been supported through an industrial grant during the graduate study with some showing that industrial support has positive effects on the likelihood of obtaining permanent academic position (Mangematin, 2000), but also that the cost of switching to industrial career from academia is lower (Mangematin, 2000), while others find no effect of industrial support on early career outcomes (Gaughan & Robin, 2004).

Studies of supply and demand of scientists have identified factors to explain entry in scientific occupation, such as salary, salary in alternative occupations (Stephan, 1996). Other important variables identified included cohort size, type of support while in school, debt level upon graduation from college (Stephan, 1996).

National studies of S&T workforces have little to say about the employment of scientists and engineers except to register the general trends in the quantities of scientists and engineers and their distributions by qualification, activity, sector and occupation (OECD, 1999). Also, due to the high level of aggregation and rigidity of the S&E indicators, such studies fail to adequately capture multidisciplinary research and research occupations mobility – for example, as is often the case today, when researchers pursue interdisciplinary, multidisplinary and cross-disciplinary work integrating various tools, methods, data, concepts and theories to address complex research questions (Feeney & Bozeman, 2005). In fact, such indicators may hide some of the most interesting indicators of processes taking place in the context of university industry interactions and affecting students' career outcomes. Such indicators also prevent researchers from gathering adequate information on narrow or emerging fields (Feeney & Bozeman, 2005), which however may have great commercial potential and thus could also be developed in the context of university-industry relations.

In addition to such limitations – part explained with the nature of the data, in part explained by their research focus - the above mentioned studies on S&T workforce exhibit two peculiar characteristics. First, training and educational policies in a technology transfer context are considered at a "system level", as interaction of different system level policy variables such as "the educational system", the "economy", and "industry". Second, and more important, the channels through which the eligible and trained students end up in the private sector seem to be under-researched. In fact, one may get the impression that universities "spit" trained graduates on the open labor market, where firms engaged in a search of appropriate employees "find" them.

Studies conducted at such level, while drawing attention to very important trends in nation's management of S&T human resources, do not provide sufficient insight into what are the circumstance in which individuals make career choices, as well as what is the relative importance of different constraints and opportunities they fact during their graduate studies. The context of graduate studies for many students increasingly is affected, or consists entirely of, research undertaken within UIRs.

My proposed conceptualization of the role of students in the context of university-industry interactions states that in many more than recognized cases university-industry interactions – and interactions between private companies and faculty in particular –

contain a component of “identification and recruitment of talent,” namely students linked to a university faculty, and involved in his or her research. I propose to consider students as an explicit variable, driving to some extent the university-industry interactions at the individual level, as opposed to considering it as a by-product of such interactions or as a mass affected by a process in which it has no role. Students are an essential link between university scientists and private companies, and might even be an important driver of certain types of university-industry interactions. For example, if students indeed have such a role, they could facilitate faculty interactions with the private sector, and also motivate the private sector to seek interactions with the universities.

Such conceptualization brings the issue of student role in private sector innovation a little more down to earth, without ignoring its macro-implications. The conceptualization proposed in this thesis is of students not as faceless flow of graduates from universities to industry, but as an identifiable and therefore specific and unique component of university-industry interactions at the individual level. It is puzzling, however, that this consideration of students is also largely absent from the family of studies examining the problem of UI technology transfer and the university scientists’ interactions with the private sector outlined in the next sections. To the extent considered, students are considered either as a “given” or as an entity upon which UI interactions have “effects.” Even though such a role for students seems more than plausible, it has somehow escaped the attention of the studies of UI interaction.

Policy assumptions and realities of UIRs

The market failure paradigm (and its reincarnations) of public support of science served as the basis for many interventions aimed at facilitating private sector utilization of university technology or of stimulating private sector research. Since the 1980s, many such initiatives[4] have been implemented in US. While I will not consider them in detail, their distinguishing characteristics are that they either 1) attempt to provide incentives to companies to engage in more R&D, 2) provide incentives, mandates (or both) to public R&D institutions to engage in technology transfer efforts, or to facilitate the university-industry interface or 3) recognize that the use of knowledge in universities is not costless to firms and provide different means to facilitate the adoption of university technology by firms.

These initiatives targeted issues such as intellectual property rights and institutional and economic incentives to undertake cooperative research. They also created more favorable conditions for public and private entities to "come together" and pursue joint research projects. The common characteristic of these initiatives is their view that universities support innovation in industry primarily through the production by universities of "deliverables" for commercialization such as patented discoveries (R. Nelson, Sampat, Ziedonis, & Mowery, 2004). Another assumption in such initiatives is that the most important channels through which university-industry interaction advances industrial innovation and economic growth are the formal channels of licensing and spin-off company formation.

This policy over-emphasis on deliverables and formal channels is indicative of a conceptual gap of interest for this study. This gap has to deal with the "interaction" component of university industry interactions (Geisler, 1995). Even though university-industry interactions are studied extensively, in most cases the attention is devoted to the incidence or products or the interaction, rather on the interaction itself. It is often

[4] E.g., Bayh-Dole act, Technology transfer act, Cooperative research and development act

forgotten that the interaction is not a discrete event to “ship” a specific deliverable (e.g. a license or prototype) to industry, but an ongoing relationship, not exhausted by a set of discrete transfers of knowledge. The necessary “continuity” of interactions is explained by the substantial recognition and absorption costs for firms, costs that are present even in absence of any institutional barriers to use university resources and technology – first to recognize commercial potential in university invention, then to assess its feasibility, and then to undertake the additional development work to actually commercialize it. As a result, even if all the conditions to ensure easy availability of knowledge to use by firms are met, the recognition and absorption of this knowledge by firms is still a costly process, and the formal channels for such absorption, while important, seem to not be sufficient.

Many studies have pointed out that publicly produced knowledge, albeit freely available, is certainly not “free” to use. Utilizing knowledge requires that some internal capacity to comprehend it and actually put it to use already exists (Cohen & Levinthal, 1990). In firms, this problem is remedied by performing internal R&D and by ensuring that the firm possesses qualified personnel capable of recognizing and acting upon technology innovation opportunities. Confirming this, Randazzesse (1996) also identified that the most effective technology transfer channels (as perceived by faculty and industry partners) are the ones involving the highest degree of human interaction (through faculty site visits, graduating students). Surprisingly, he also identifies that these are among the least used mechanisms (Randazzese, 1996). This surprise is, of course, in part due to the difficulty of “formalizing” inherently unpredictable process such as the ongoing communication between research partners. Nevertheless, the policy focus on formal (albeit specifically designed) arrangements to facilitate university-industry interactions will fall short of success unless it recognizes and exploits, to the extent possible, the potential of less structured (i.e., informal and non-contractual), but extremely important interactions.

Focusing on the role of students offers up an interesting middle ground to study the importance of the human component of technology transfer, without entering the realm of the fuzzy discussion of what exactly constitutes informal interactions and what are exactly its outcomes. While the role of students in technology transfer may be best understood in the context of informal faculty-industry interactions, the implications of students are all but intangible. As Randazzese remarked, “one of the best ways to transfer technology is to transfer the people associated with it” (Randazzese, 1996, p. 397).

In the case of students, this occurs *not only after* these students graduate and find industrial employment, *but also while* they are students and work for faculty interacting with industry. In doing so they are essential in the experimentation phase of adoption of new technology where they can work with industry personnel on resolving technical problems which, while important for the commercialization of the technology, may be of little value and interest for the faculty member. Similar mechanism is acknowledged by Thursby and Thursby (2004) who found that 77% of the licensed inventions required some form of further faculty involvement in the commercialization, in order to make further development possible.

This mechanism may be far more common than generally acknowledged. For example there are several ways in which universities and firms may get involved in cooperative research, which can be placed on a continuum ranging from a situation where the firm contracts out certain research to be accomplished by the university to a situation where the university develops a commercial product and contracts with a private company to produce it (Poyago-Theotoky, Beath, & Siegel, 2002).

However, the most common scenario may be in between these extremes and be an intermediate situation, when the university has conducted some basic research that has potential commercial applications. These applications are still in an embryonic stage, although the fundamental work has been made available through the official channels. Only a fraction of the knowledge is codified, and a lot of additional work is required to develop these new ideas into knowledge material actually amenable to commercialization and development efforts. In such cases, the necessary information is conveyed within an ongoing university-industry relationship, where the firm and university scientists exchange information while the firm attempts to commercialize the embryonic invention (Poyago-Theotoky, Beath, & Siegel, 2002). Again, this process is likely to require the involvement of the scientists inventors as well as the continuous assistance of their graduate students. The students may not be the primary inventors but in most cases are qualified to provide the assistance needed in post-invention phases.

To sum up, most of university-industry interactions are likely to be between the direct funding of specific research by industry and university spin-offs, in a fuzzier area where both firms and university scientists jointly explore problems of mutual interest and where both sides get what they need. For scientist this being a (funded) opportunity to explore new challenging problems, while for industry this is an opportunity to acquire deeper insight in a technological area while solving specific technological problem (Slaughter, Campbell, Holleman, & Morgan, 2002). In this work environment the role of students is more than likely to be crucial. In order to sustain such work environments, scientists and industrial partners alike need to rely on a pool of qualified personnel, capable of accommodating the experimental and technical work associated with such semi-directed searches of solutions to problem. In this experimentation stage students are perhaps more crucial than any other collaborators that a scientist may have as the work involved is perhaps valuable for the student training, but of little or no interest for scientist's colleagues. Hence both the increased dependence and reliance on students for research in interactions with industry relative to "normal" university research. To paraphrase Slaughter and colleagues (2002) "one can't be a professor unless he does research, and a professor cannot do research without graduate students" (Slaughter, Campbell, Holleman, & Morgan, 2002, p. 288), but probably one can't even be considered for research partnership with industry unless he already has a stable pool of graduate students. While for collaborations with other scientists it may be sufficient that researchers simply share common interest, data and the like, the presence of students is perhaps a necessary condition for any interaction with industry to occur.

Some authors identify this experimentation phase as a separate stage in the technology transfer process, and argue that it is critical precondition determining whether or not an invention will get transferred at all (Randazzese, 1996). I argue that students are a critical asset in accomplishing this stage because they possess the skills to solve the implementation problems expected in such post-invention stage and their involvement may be desired both by the sponsoring scientist (who may have little interest in the more technical problem solving activities expected in this stage) and by the firm (who has the double incentive of utilizing the know-how embodied in students to solve the commercialization problems, and to also identify and train potential future employees in the process).

Considering these features of students, it is surprising that they have not been devoted more space in studies of university-industry interactions. Firms are certainly looking for a variety of outcomes when interacting with universities, such as solutions to particular problems, new ideas, new directions of research, and there is nothing that implies that the “look up” and evaluation of promising students is not an integral part of this process, but a separate activity. It seems that, while not necessarily so in reality, according to technology transfer and UIR scholarship, students and firms meet mostly through career fairs and human resource offices, but not while involved in research of mutual interest under the auspices of a sponsoring university professor. Studies of UI interactions mention students only in passing.

Technology transfer channels in UIRs

A set of studies has highlighted the variety and importance of channels of technology transfer from academia and industry other than patenting and licensing or startup company formation. Researchers have shown that university-industry links are characterized with much broader set of activities (Agrawal, 2001; Agrawal & Henderson, 2002; Cohen, Nelson, & Walsh, 2002). In particular Cohen et al. (2002), document that, with the usual exception of pharmaceuticals, the most important channels for transferring university knowledge to industry include informal interactions such as conferences and meetings, formal consulting, hiring graduate students and personnel exchanges (Cohen, Nelson, & Walsh, 2002). The process of UI knowledge transfers occurs through multiple channels such as personnel mobility, informal contacts, consulting relationships, joint research projects, and patents; licenses and new startups represent only a portion of this process.

Most studies of university industry relations are predominantly descriptive, and focus either on the expectations of the parties of what would they gain, or on the actual or perceived benefits accrued from the participation (Geisler, 2001). Overall, there is void of information about the nature of the industry-university interaction that occurs when the two informally partner in an research partnership (Hagedoorn, Link, & Vonortas, 2000). Such informal interactions (between universities and industry) generally aim at exchanges of up-to-date knowledge, problem solving, sharing of equipment and instrumentation, gaining access to students and faculty, the solution of specific problems (Mansfield & Lee, 1996). However, some observers caution that the expectations that academic researchers will shift their work to more applied and industrially relevant work is unwarranted, and more importantly – inappropriate, a view shared even by industry representatives themselves (Rosenberg & Nelson, 1994). Therefore, the key question of interest becomes not whether universities successfully meet the needs of industry by “working for industry”, but whether they are successful in exploiting the complementarities that reside by definition in these relationships.

Some studies have identified such complementarities at the individual, informal level. For example, Kreiner and Schultz (1993) characterize university-industry interaction in the Danish biotechnology community as an informal barter economy wherein private companies and universities “liberally” share information per community norms that encourage such free flow of information (Kreiner & Schultz, 1993). Boardman and Bozeman (2006) draw similar findings from case study, characterizing informal interaction across sectors as uncodified barter systems employing norms that may or may not become institutionalized with time. Slaughter et al. (2002) demonstrate that students are crucial component of such informal bartering, and are the “token of exchange” given by professors to industry in exchange of funding (Slaughter, Campbell, Holleman, & Morgan, 2002).

Studies of UIRs that explicitly consider students

The presence of students in universities (and university hosted technology-transfer initiatives) may be the key distinguishing factor of universities relative to other public science and technology suppliers, such as the federal laboratories (Bozeman, 2000). “The presence of students makes a remarkable difference in the output, culture and utility of research” (Bozeman, 2000, p. 636). Students are not only a “reservoir of cheap labor” supporting university research, but are *also means of technology transfer* through post-graduate job placements and they “often provide the social glue holding together many faculty scientists and the companies they work for” (Bozeman, 2000). While the firms seem to acknowledge that the most important outcomes of interactions with universities is access to students they could hire (Roessner, Ailes, Feller, & Parker, 1998), scholars of technology transfer do not seem to give this phenomenon the direct attention it deserves. The underestimation of the role of students is evident in labeling them as partially responsible for “random technology transfer” (Nataraajan & Chawla, 1994), while in fact their role may be quite central in university-company interactions. While the technology transfer literature has considered numerous “transfer media”, the role of students seems to have been neglected.

Although many studies focus on graduate student socialization, they rarely specifically identify graduate students involved in university-industry relations (Anderson, 1996, 2000; Anderson & Louis, 1994; Anderson, Louis, & Earle, 1994; Anderson, Oju, & Falkner, 2001). Nevertheless, a set of studies highlights the importance of students in university industry interactions either in terms of effects on students, or in terms of benefits to firms and specifically deals with students in the context of university-industry relations. Studies from the first group raise concerns such as that industrial involvement leads to restrictions on intellectual property and resulting ability to publish, thus potentially having negative impacts on these students' careers (Slaughter, Campbell, Holleman, & Morgan, 2002). More importantly however, Slaughter et al. show that graduate students are in fact the "token of exchange," the "gift" from the professors to industry in exchange for funding support. Unfortunately, the content of this promising study does not match well its title. The authors focus predominantly on the implications of interactions with industry for the academic freedom of students (as perceived and interpreted by faculty) and devote only the last section of the paper on speculating about different mechanisms through which graduate students link university professors and industry. (Slaughter, Campbell, Holleman, & Morgan, 2002).

With the above exception, only a few studies address how interactions with industry shape graduate student training (e.g. Bozeman & Corley, 2004; Croissant & Restivo, 2001; K. S. Louis, Anderson, & Rosenberg, 1995). Croissant and Restivo (2001) for example report that student participation in industry-related programs does not appear to change their skills and career decisions, but powerfully and positively elevates their valuation of academic values such as peer recognition and intrinsic rewards. Louis et al.

(1995) report that entrepreneurial behaviors at the level of the department might be related to scientific misconduct and research values. Bozeman and Corley (2004) report that faculty who have stronger industrial orientation are also more likely to be mentors (Bozeman & Corley, 2004).

Conclusions and preliminary model

If one reads them closely enough, most of the studies mentioned above provide (albeit in many cases indirectly or even unintentionally) a set of propositions regarding the role of students in the interactions between the academic and industrial sectors. What is needed is a model to tie these disconnected propositions, explicit and implicit, into a more stable network of causal paths that will in turn serve as the foundation for assessing the relationship between university scientists' student-related behaviors and these scientists' interactions with the private sector. The remainder of this literature review I devote to outlining how to use the many above discussed propositions in building a model to test the central question of this thesis. Therefore my task now shifts from review of the extant literature to the synthesis thereof.

The variety of studies on university industry interactions may mislead one into believing that there are multiple competing theories explaining the nature and the reasons of occurrence for inter-sector collaboration. However, a closer look reveals that the theories dealing with the problem can be classified in two broad categories: interdependence theories and interaction theories (Geisler, 1995). The interdependency theories focus on the impact of the external environmental factors, while the interaction theories explore the internal development of the relationship itself.

The implied causal mechanisms lurking at the back-end of the policies to encourage university-industry interactions tend to fall in the interdependence categories. The government has limited capacity to influence behavior at the micro level by means other than proposing institutional frameworks and sets of incentives that policy makers believe will steer the relevant groups into the desired direction.

Nevertheless, evidence from within the set of interactions theories suggests that relationships evolve through the growth in influence of commitment, trust and communication patterns. Continued interactions, prior relations and beliefs, mutual trust and commitment result in the emergence of inter-organizational relationships, and help sustain the relationship once formed on the basis if such factors (Geisler, 1995).

Obviously, no national policy can rely on prior relations and beliefs to make adjustments to the national innovation system. It is possible, however, to incorporate insights from interaction theories in designing institutional frameworks. As far as students are concerned, they have not been considered as components of such initiatives, except to the extent that certain boundary-spanning institutional arrangements (e.g. ERCs), contain a curriculum development component.

The model proposed in this thesis attempts to provide integrative framework combining features of interdependence and interaction theories of university industry interactions. The role of students in university-industry interactions is a factor that allows the meaningful combination of these two types of theories, that would represent more than the sum of its parts. Elements from many (if not most) of the above discussed studies, as well as new elements I introduce in the model development component of this study, may be incorporated into the framework.

The studies reviewed at the beginning of this chapter implied that, for a variety of market failures and societal values, universities are the best supplier of trained workforce to meet the human capital demands of industry. In this way, and in their other missions such as producers of basic research, they become worthy partners of many technology-intensive industries, occasionally resulting in specific alliances – exactly as the interdependency theories would suggest. Correspondingly, the goal of much of the government policy in science and technology has been to provide optimal conditions for the inherent interdependencies between universities and industry to develop. Most notable among such efforts have been policies and institutional arrangements to create incentives for closer UI interaction as well as for the removal of some of the barriers for industrial utilization of the university knowledge.

The set of studies on technology transfer pointed out that technology transfer interactions, more often than not, require considerable interpersonal involvement, even when the institutional preconditions for the interaction are present. These two types of findings, however, miss an underlying common denominator. Concluding that both types of factors matter is not yet a theory. Explicit consideration of the role of students (in the context of university-industry interactions at the individual level) provides an opportunity for logically linking these propositions.

Students are appropriate to address the gap between interaction and interdependency theories. On the one hand, the academic sector addresses the market failure problems pertaining to private sector innovation at the societal level: it generates the pool of basic knowledge and the pool of human resources necessary for firms to innovate. In doing so it remedies the disincentives of firms to produce these key innovation inputs at a socially desirable level. This type of models implicitly assumes that once such inputs are created by means of public support, the private sector costlessly taps into them.

The interaction theories show that the process of identifying and using knowledge, and the process of identifying and training labor force are far from costless and involve the need of continuous interactions and prolonged exchanges. While the presence and importance of informal channels of UI interaction is widely acknowledged, its particular role at the system level is unclear. For example, are informal interactions antecedents or correlates to actual collaborative research?

Some theorists suggest that the bulk of university-industry interactions can be described as an “experimentation stage” located somewhere between the recognition of a possible commercial application and technological problem solving (Poyago-Theotoky, Beath, & Siegel, 2002; Randazzese, 1996). In such interactions, university and industry personnel continuously communicate and jointly attempt to resolve the challenges associated with transforming embryonic knowledge into commercially viable technology.

When firms interact with universities, their expectation is to make progress on solving such problems, develop their internal capacity, gain access to the university knowledge and skills, or all of the above. On the other hand, much of this “semi-basic” “semi-applied” work is performed by or heavily relied upon graduate students. Considering the high levels of uncertainty that any tangible outcome will result from the interaction, and considering firms’ persistent need to identify and recruit talent as a tool to build capacity to address such problems in the future, and the time demands that work for industry would put on a scientists in the absence of students, the role of graduate students is better conceptualized not simply as a technical personnel, but as an asset motivating the firm to enter an UI interaction. An asset that, even in the case of failure of a specific R&D project, can be taken away either partially (by means of acquiring tacit knowledge on the basis of interacting with faculty or graduate students) or completely (by sustaining a relationship with the university scientist and establishing connections with possible recruits from within the students working on the project.)

Considering these features and roles of students, it is plausible that access to students is an explicit motivation for firms to seek interactions with universities. This claim also has a theoretical value as it allows integrating the “interdependence” and “interaction” components of UI interaction. Since it is already known that among the chief reasons for firms to pursue UIRs is access to expertise and to instantaneously communicated research results, and since it is repeatedly found that most of university embryonic inventions require substantial post-disclosure involvement from the university side, it is all but understatement to claim (which this thesis does) that firms are particularly motivated to seek access to students within the frameworks of whatever strategies for university interactions they have. Consequently, university scientists who maintain larger pools of students and in generally are more involved with students will be more likely to interact with industry. After outlining the theoretical reasons for such a claim (which summarizes the central question of this thesis), the remaining chapters will discuss the empirical evidence whether such a claim is justified. Before stating a strong version of such claim, however, it is necessary to state the specific hypotheses implicit in such claim as well as postulate the complete system of variables. Even though this chapter showed numerous reasons to consider students as central to university-industry interactions, a mechanism describing the role of students in UIRs is still needed. The articulation of such a mechanism is the goal of the next chapter.

3. HYPOTHESES

This section translates the research questions set forth in Chapter 1 into specific hypotheses. The chief dependent variables of interest are different types of interactions with the private sector. The models developed below estimate the extent to which such industry-related behaviors are reinforced by involvement with students (e.g., through grant support or research collaboration). This thesis does not attempt to provide a comprehensive prediction of private sector involvement, but focuses on the role that faculty interactions with students may play in faculty interactions with the private sector. Nevertheless, implicit in this intent is the claim that students are an important factor in university-industry interactions at the individual level.

First, I outline the specific hypotheses pertaining to the relationships between student- and industry related behaviors of university scientists, and then (in Chapter 4) I develop the full model accounting for spurious and indirect relationships. The basic relationship postulated in this research is that raising one's level of involvement with students is associated with a raise in the likelihood that a scientist would engage in interactions with industry as well as with an increase in the intensity of such interactions.

Considering that the research questions concern several student related behaviors (e.g. grant support, collaboration, teaching etc.) as well as different types of industrial interactions (e.g. co-authoring papers with industry personnel, collaborative research, information exchanges, etc.), the thesis will be based on the estimation of several models.

I outline the rationale for hypothesizing a generally positive relationship between student involvement and industrial interactions. Then, I describe the particular mechanisms through which the general underlying mechanism works in every specific student related behavior.

General hypothesis - rationale

The general hypothesis of this thesis is that more intensive involvement of university scientists in a spectrum of student related behaviors has direct positive effects on the probability that these scientists enter various interactions with industry as well as the intensity of these interactions.

While the preceding chapter outlined the major role which students may play in university-industry interactions and showed why it is plausible that students play far more important role as driver of university-industry interaction than is commonly acknowledged, what is missing from previous study is articulation of the specific processes that causally link involvement with students and involvement with industry (at the level of the behaviors of individual scientists). A necessary next step is to provide justification for the general claim of this thesis that more intensive student involvement of university scientists causally drives, at least in part, the likelihood and intensity of scientists' interactions with industry.

The intuition behind such reasoning is that research work in academia and interactions with industry are becoming increasingly complementary. The trend, as outlined by Owen-Smith (2003), is characterized with convergence of public and private science. From divergent realms only two decades ago, the academic and industrial successes are becoming complementary. The success in one of the activities increasingly fuels success in the other, and vice versa.

Though I provide an extended review below, the general rationale underlying this study's hypotheses predicting a positive relationship between university scientists' student and industry interactions is that given the evidence of complementarity and reinforcement of success across the academic and industrial sectors, more intensive involvement with students is one dimension of scholarly success that also reinforces commercial success. Involvement with students in different capacities constitutes a dimension of scientists' research capacity such that it is greatly valued by industrial partners and provides both more incentives and ability for industrial partners and the scientist himself to engage in various types of interaction, relative to scientists less involved with students.

Science and technical human capital and rewards in science

Many researchers have pointed to the puzzling phenomenon of highly skewed distribution of scientific outputs and assets. This is particularly evident in the cases of productivity and recognition: disproportionally high share of these assets is concentrated in small group of scientists (David, 1994). The emphasis in explaining these phenomena in the literature has been on the "accumulative advantage" (Merton, 1968), reinforcement (David, 1994), or both (Fox, 1983).

This phenomenon of accumulative advantage, dubbed "the Matthew effect" (Merton, 1968) has been described as "the accruing of greater increments of recognition for particular scientific contributions to scientists of considerable repute and the withholding of such recognition from scientist who have not yet made their mark." (Merton, 1968, p. 58). Some have been more specific in describing the phenomenon of "accumulative advantage" as the ability to leverage past success into research funding.

(Allison & Stewart, 1974; J. R. Cole & Cole, 1973). The pattern of increasing returns on productivity in terms of recognition, will then in turn allow the scientists to capitalize on this recognition and transform it in grant support, collaborations, and priority in cases of independent multiple discoveries (Fox, 1983).

This emphasis may have been misplaced (Dietz, 2004), and moreover the accumulative advantage hypothesis is very difficult to test empirically (Fox, 1983). Instead of focusing on prestige and initial career advantages, it may be the case that human and social capital advantages (not just prestige and recognition advantages) account for success in science (Fox, 1983). Success on the other hand, especially nowadays, is not necessarily entirely exhausted by the number of quality of publications, but also relates to the extend to which scientists build, expand, upgrade and develop their scientific and technical human capital, defined as “the sum of researchers’ professional network ties and their technical skills and resources” (Bozeman & Corley, 2004).

The importance of the STHC theory is in highlighting the central role of social capital to science and to demonstrate that success in science is explained not only in terms of human capital assets, but also in terms of tacit knowledge, know-how and social ties and ability to access and exploit social networks. Certain STHC endowments facilitate traditional outputs (e.g. publications), but they also facilitate the further development and accumulation of STHC.

This mechanism is important for the argument advanced here because it emphasizes that some specific dimensions of individual scientists’ STHC (and not just their publication record) can explain different ‘successes’ (for example, further enhanced publication productivity, but also enhanced ability to form cross-sector and crossinstitutional ties). (e.g., productivity and resulting reputation and research capacity), but not general ability of motivation explain the variance in opportunities for interaction and grant support of scientists. Avenues towards recognition may be more diverse and involving wider cross-section of scientists abilities and endowments than implied by the accumulative advantage hypothesis.

Nevertheless, the “skewness” phenomenon and its conceptualizations and explanations (e.g. the Matthew effect or the reinforcement hypotheses) are important in directing research attention that indeed not all, but only some of the outputs and the activities of scientists are “truly” rewarded. The importance of the STHC theory is to provide concepts and evidence that the set of assets or endowments rewarded in different circumstances may be broader, and it also provides insights that the nature of rewards may be broader as well to include merely the further development of one’s STHC. In terms of the present argument this is important because the conceptualization of students put forward here is that 1) students represent important dimension of scientists STHC 2) such that it enhances these scientists ability to identify and act upon industrial opportunities and also makes them more attractive partners for industry colleagues.

Whether this launches a mechanism of reinforcement or accumulative advantage is irrelevant. What is essential however is that the mechanism hypothesized here fits an existing conceptualization of scientists’ technical and human capital that provides explicit treatment of how “non-prestige” endowments result in future rewards. Such rewards include not only general enhancement of scientists’ capacity to “do science” (in ways encompassing not only their scientific ability, but also their social ties and tacit knowledge as acquired and modified in their respective social networks), but one such rewards is the further enhancement of the scientific and technical human capital itself. Involvement with students fulfils both of these goals as it contributes to ability of scientists to interact with industry both directly (through constituting a pool of resources particularly appropriate to research involving industry partners) and indirectly (for example, by expanding and consolidating the social networks of scientist which may result in further future interaction opportunities.)

This thesis does not imply that involvement with students is the primary explanation of scientists' interactions with industry, but it does imply that students are an asset, returns on which (in terms of industrial interactions), may be relatively higher than returns on other typical assets, such as publication productivity, or "general" scientific ability and motivation. This thesis does not claim that this link constitutes a particular case of "accumulative advantage", but it uses and insight from the accumulative advantage theory that directs research attention to the fact that very specific and definable assets determine success, but not general interest and ability. If students are one such assets, marginally higher involvement of scientists with students will also result in marginally higher involvement with industry.

Recognition – derived from scientists' scholarly contributions (published work) - is so important in science because the recognition from the community of scientists is tied to the key rewards valued by scientists, such as salary and job tenure, and access to human resources and physical facilities that scientists need to produce published results (David, 1994). For the scientists as individuals recognition may be an end in itself (intrinsic rewards to science), but for their colleagues and stakeholders, the recognition is a ticket issued to scientists who have accumulated measurable contributions and research assets. Recognition is not an ethereal layer of appreciation slowly growing around a scientist simply as a by-product of his devotion to science, but is the de-facto acknowledgement of his or her ability to stock up particular assets such as particular contributions, skills, linkages etc. Even though the behaviors expected from scientists are very diverse, and feature numerous activities numerous activities, besides research (e.g., teaching, committee and administrative work, teaching advising), when it comes to the distribution of rewards, scientists who had had the poor fortune (or judgment) to emphasize behaviors diverting them from publication, are typically left behind. They still may be good scientists – in some respects even better ones than that scientists only engaging in the bare minimum of non-publishing activities, but unless they keep up in the top publishing percentiles of their disciplines, they will be punished with less opportunities and recognition in the future.

An implicit institutional assumption that supposedly negates the above possibility is that the better scientists will be better in all they do – which would lead one to expect that scientists who publish more will be better teachers, collaborators, administrators etc. There may be some merit in this assumption. However, valid or no is not the issue here: the academic reward system rewards very particular contributions, and not one’s overall “scientific citizenship”, best exemplified by the “publish or perish” adage. The implication for the current study is that the Matthew effect is one of a metaphorical gateway directing attention to inputs and outputs to science that matter in particular social context (but not ones presumed by ideal type conceptualization of science as a pursuit of knowledge etc.). As indicted above, the hypothesis tested here does not imply that interaction with students trigger accumulative advantage or reinforcement mechanisms.

This may or may not be the case – the problem is beyond the scope of this thesis. However, this study claims that students are a component of scientists STHC that may lead to greater recognition from industrial partners (and as a result – more interaction with industry), for scientists who have relatively overdeveloped this dimension of their research capacity.

Recognition in itself is not such an asset. Recognition is the reward to scientists who possesses assets that "matter" (typically publication productivity). This thesis suggest that, after all, assets that lead to differential recognition and opportunities may not be so one-dimensional, and in some context – like interactions with industry – feature some other aspects of being a scientists, such as the interactions with students.

Interactions with industry contain a "recognition" component. Even if a scientist proactively and independently, for whatever reason, seeks to enter some kind of interaction with industry, his usefulness for such interaction will be assessed by the possible industrial partners. The scientist's ability to make the interaction meaningful for the industrial partner will be assessed. Alternatively, how do industrial partners chose particular scientists to collaborate with, among the many scientists with similar interests and expertise? Which one of the many scientists in a big aerospace department who work on combustion will enter interactions with industry relative to his colleagues with similar expertise and credentials?

Scholarly success in a particular field as measured through publications will certainly weight in such decision (by industrial partners). However, it is unlikely that it will determine whether or not the interaction will occur. In fact, since many university-industry interactions are informal, the relevant assets in such relationships are likely to be more diverse and to relate to more aspects of the role of a scientists rather than mere publication record. The role of students as input in research and university industry interactions implies that faculty's involvement with student may in fact be such an asset contributing to recognition and utilization from industrial partners.

The explicit delineation of the dimensions along which university based researchers compete (but not implicitly assume that "all that matters is publications") is warranted by the directions in which the science enterprise has evolved (David, 1994). With this in mind, focus on publications may have been not only an inherent measure of what matters in science, but also a function of the dominant mode of support and competition in science such as the large-scale, peer-review dominated government support science. Newer trends however suggest increased competition for funds, most visible in fields with high team size and resource-equipment requirements. Another, much more recent trend, is the closer incorporation of interactions with industry in the university research. It is only plausible that scientists and institutions would adjust in accordance to the constraints, opportunities and rewards of this newer institutional environment. One such adjustment may be a shift in the relative importance of the different aspects of scientists' research capacity, for which mere publication productivity is not necessarily the only proxy anymore. If so, differences in distribution of different assets (e.g., involvement with students) while previously unimportant may lead to differential outcomes in some arenas of new academic competition (e.g. interactions with the private sector).

In this thesis, the various types of interactions with industry of interest are de-facto examples of particular mechanisms through which recognition from industrial partners takes place. No scientist will be sough after for information about research or provided such information, offered consulting opportunities, collaborated with on commercializing technology or co-authoring papers unless he or she possesses reputation and research capacity of relevance for these industrial partners. These forms of interaction therefore are a form of recognition, and the primary hypothesis of this work is that what drives this recognition is not necessarily mere productivity of the scientist in his or her field, but also the extent to which he possesses the capacity to work with students thus creating for himself and environment in which to meaningfully explore the research or collaboration opportunities with industry. In the context of grants, this means that as indicators of past successes, they will predict future interactions with industry, which is demonstrated by Bozeman and Gaughan (2006).

Scientists' research capacity is a fuzzy concept and may incorporate various heterogeneous elements. It includes not only scientist's formal credentials, but also his or her collaboration experiences, tacit knowledge, etc. acquired over one's scientific career. This constellation of assets is conceptualized as a "scientific and technical human capital" (Bozeman, Dietz, & Gaughan, 2001) and emphasizes the heterogeneity of assets scientists may employ to further develop their research capacity and their careers. If the components of a research capacity are heterogeneous and if the recognition can come in many forms (or at least grant funding is increasingly accessible through a variety of diverse sources), then it is plausible that some aspects of research capacity are better suited for some forms of acknowledgement (or grant funding) than others. The implication of this possibility for the present work is clear: if industrial firms are one such sort of grant funding, then the relevant question is what aspects of university scientists' research capacity are relatively more likely to be valued more by industrial partners. What is the mechanism through which such advantages may take place?

At least part of the explanation relates to choices made by scientists in their careers. The most crucial of these choices are the "scientific races," or the particular problem fields that young scientist would enter – "the winner-take-all character of scientific contests dictates that scientists choose the contests they enter with care" (Stephan, 1996). Young scientists, in particular, must be careful in choosing their scientific contests if they are to successfully signal their ability or resource worthiness and set in motion processes of accumulative advantage.

Students as investment in research capacity

Another important set of choices scientists consider is strongly dependent on their choice of problem field: the choice of how to allocate their grant support. How scientists allocate the grant funding they acquire is dependent but perhaps not completely determined by their disciplinary and problem affiliation. Scientists may exhibit preferences for different types of research (e.g. on the basic-applied spectrum), may employ different collaborative strategies, and most importantly – may choose to relatively over-develop different dimensions of their research capacity and resources. For example, for some fields and some scientists it may be more important (given their scientific goals) to equip and maintain a lab. For others, it may be more important to establish collaborative links. Yet another possibility, the one that is the focus of this study, is that of a *scientists attempting to pursue a broad portfolio of research and relying on multiple students and post-docs to accomplish the work* (past the idea origination, promotion and funding stages). In sum, there are numerous ways for a scientist to channel the research support he receives – he may choose what aspects of his or her research capacity to enhance by means of grant support. One such aspects that may or may not be chosen as important to enhance is students. More importantly for this argument, the level of involvement with students is not entirely predicted by structural (disciplinary or institutional) characteristics, but also depends on the individual scientist's motivations, research preferences, and research strategies.

In the last chapter I outlined plenty of reasons for considering students as an active component of UIRs, and as an asset for the university scientists contemplating interacting with private companies. Students, although in passing, are acknowledged as a key resource in the production of research. The resource requirements for producing science involve access to substantial equipment, and the assistance of numerous graduate students and post-docs (Stephan, 1996). The particular role and importance of students for the research process, however has not been well documented. The general conclusion is that in most fields, students are a necessary component of research (Stephan, 1996).

Other than this acknowledgement, there is no evidence regarding the particular role of students in certain research outputs. While not focusing on research products per se, this thesis estimates the effect of students on the likelihood of certain research arrangements, in particular ones involving university-industry interaction. This intent is grounded in the observations made above that the research capacity of a scientist is in fact a 1) heterogeneous concept and may consist of various, differently emphasized parts, that 2) different funding entities may value different components of research capacity differently and hence base at least in part their judgments regarding the "grant worthiness" of a scientist on the extent to which the scientist possesses the research capacity particularly valued by the specific funder. Lastly, the preceding chapter showed that there are a number of reasons to suspect that access to students is among the chief incentives for industry to engage in university-industry collaborations, even when the goals of collaboration are specific.

Students are a dimension of research capacity particularly valued by industrial partners in UIRs and hence that university scientists more heavily involved with students, de facto possess research capacity that makes it much more likely for them to enter and sustain interactions with the private sector relative to their colleagues of similar disciplinary background and credentials but who interact less with students. If this reasoning is valid, than a formal test would reveal that higher involvement with students is associated with higher level of interactions with industry.

General productivity and scientific reputation are insufficient such factors to explain interactions with industry, since all else equal, any funding source would of course prefer scientists with longer and stronger publication record. In the context of university –industry relations, involvement with students, at the very least is better (than the productivity) measure of general capacity explaining scientists entrance in such relationships. At best, this is a dimension of research capacity not fully explained by general productivity and may have direct effects of its own.

Regardless of which of the above two scenarios is at work, the reasoning behind the main hypothesis does not change. The overarching hypothesis of the present work is that more intensive involvement with students in different capacities constitutes a dimension of scientists' research capacity such that it is greatly valued by industrial partners and provides both incentives and ability for industrial partners and the scientist himself to engage in various types of interaction. Hence the positive hypothetical relationship between student involvement of scientists and the resulting higher likelihood of entering interactions with industry and the higher intensity of such relationships.

Industry may value students particularly strongly relative to other assets or outcomes in university industry relationships. I broadly interpret the intensity of different types of university scientists' involvement with students as indicative of an important dimension of their research capacity: to be successful disseminators of new knowledge (teaching), to be successfully capitalizing on their scientific reputation and skills (grants support of students), to be successfully embedded into various professional networks which they expand (interest in mentoring of students), and to be active generators of new ideas and utilizers of research opportunities (research collaboration with students). The importance of this particular dimension of research capacity however is amplified the above discussed fact of it being integral to core functions of universities in general and by the particular role that students play in the interactions between universities and industry.

Hypotheses

Then general reasoning outlined below holds across different specific student related behaviors. In the hypotheses below I define the expected relationships between key aspects of the faculty-student relationships and faculty interactions with the private sector. The faculty-student relationships considered in these hypotheses are:

- teaching activities (average hours per week spent teaching)
- advising (average hours per week spent advising students for curriculum and job placement)
- mentoring orientation (degree of interest in mentoring graduate students)

- grant support of students (number of students supported through grants or contracts on which the university scientist is a PI)
- research collaboration with students

The interactions with private sector (dependent variables) are measured through 10 variables - 9 dummy variables: one for having any working relationships with private company during the past 12 months, and 8 for specific types of interactions, and one continuous variable – percentage of research time spent working with researchers in the private sector. I also use a summary measure of scientists' industrial involvement – the industrial involvement scale proposed by (Bozeman & Gaughan, 2006).

Each hypothesis below should be interpreted as an illustration of a particular instance of how particular type of involvement with students may in effect constitute a source of accumulative advantage by increasing the likelihood of the scientist to enter interactions with industry as well as the intensity of such interactions.

H1: *University scientists who support more students through grants are more likely to interact with industry.*

In accordance with the general hypothesis that students represent a dimension of scientist's research capacity particularly relevant for the pursuit of research interactions with the private sector, the core of the hypothesis remains that the larger pool of students a university scientist supports (hence has at his or her disposal), the more likely is that he or she is better positioned to successfully engage in interactions with industry.

Considering the general emphasis on conceptualizing students as dimension of research capacity, supporting students through grants represents a direct investment in such research capacity. Performing research involving the maintenance of a pool of students delivers the basic preconditions for engaging in collaborative research with industry. Researchers who support more students through grants effectively invest in maintaining a pool of human resources that they could easily deploy to tackle various research problems. This type of flexibility as well as the type of work most likely to be performed by students (e.g. experimental, prototyping, software writing and testing), is what both makes the university scientist capable of acting on industry related opportunities. But this is what also makes him an attractive partner for industrial collaborators: the presence of students to advise on equipment issues, write and troubleshoot software, perform tests and experiments is likely to be crucial at the "experimentation stage" (Randazzese, 1996) in university industry interactions.

The graduate student stipends are the responsibility of the university scientist. Success in securing grant funding is one of the major criteria to evaluate the performance of faculty. However, how faculty allocate their grant money is not rigidly specified in any way and is mostly, but not only, a function of the types of research problems they chose to engage in. While certain problem field choices naturally come with requirements for expensive equipment, others involve maintaining a lab pursuing long-term research, yet others involve handling a portfolio of projects allocated among stable graduate student and post-doc workforce. However, there is also a "personal work style" component to these choices. For example, scientists of equal credentials, reputation and accomplishments may differ considerably in research preferences, even if working in the very same field. Consider the scientist who pursues a large portfolio of collaborative projects with other universities that require limited labor requirements but high creativity requirements, and thus he only maintains a small pool of PhD students, versus the scientist pursuing very narrow research agenda dealing with problem solving, simulations, testing - activities for which he relies on a large pool of graduate students, for example. Unlike research preferences, number of students supported is easily measurable, and this hypothesis states that the mere presence of more students enhances the scientist's likelihood of entering interactions with industry and the intensity of such interactions. Whether or not number of students I a proxy of type of research being done is irrelevant for this hypothesis. Moreover, controlling for disciplinary affiliation, productivity and grant success will suffice to isolate the direct effect of students.

Auxiliary hypothesis

H1A: *Number of master's students (as opposed to doctoral) supported is a weaker predictor of industrial interactions.*

At a first look, considering that master's student more likely than not have industry-related career aspirations (Behrens & Gray, 2001) while PhDs are more likely to be groomed for academic positions one could think that support of masters students will be more strongly associated with interactions with industry. One could argue, in many ways masters' students may be a more appropriate workforce for certain industrial projects – projects which require problem solving capabilities and application capabilities but not necessarily knowledge of the cutting edge research in a field.

This reasoning however is faulty from the standpoint of the arguments advanced here. If industrial companies are motivated by accessibility to highly trained human capital with advanced knowledge, the presence of doctoral students is likely to be of much greater importance than the presence of masters students, who are typically hired on entry level positions and are available in greater supply on the labor market. Thus it is expected that doctoral students will have stronger impact on industrial interactions in all of the models.

H2: *University scientists who collaborate with more graduate students will also be more likely to interact with industry.*

One justification for this hypothesis is the fact that graduate students are often the ones who conduct the research once its objectives and parameters of the research are specified (Behrens & Gray, 2001). Moreover, Bozeman and Corley (2004) report that scientists who have stronger industrial orientation are more likely to have mentoring orientation in their collaboration strategies, a behavior also predicted by the number of graduate students they collaborate with (Bozeman & Corley, 2004). With this in mind, I suspect that university scientists who are more active collaborators with graduate students will also be more active in collaborations with the private sector, but perhaps for some and not other types of collaboration. Lastly, more intensive collaboration with graduate students may be indicative of scientists' ability and propensity to generate and pursue new research opportunities for which he can easily recruit and work with graduate students – fact that is also probably valued by industrial partners.

The literature on scientific productivity suggests that scientists who collaborate with each other are more productive, often times producing "better science" than are individual investigators (Stephan, 1996). Moreover, collaborative work also is more likely to be based upon funded research and more likely to be experimental rather than theoretical. Thus collaborating with students will seem to be a function of research particularly relevant for industry because 1) presence of funded research is a prerequisite for being able to work with students (typically hired to work on a project since it's the scientists' responsibility to secure student stipends through grants) and 2) students are much more likely to be involved with experimental work – usually technical and thus easier to delegate to scientists who are still in the process of receiving their training, rather than scientists' peers. Hence the expectation that collaborating with students will also be associated with more active interactions with industry.

H3: *The more time university scientist spends on teaching, the more likely he or she engages with private sector researchers.*

I hypothesize that this is a quadratic relationship – at least "ideally", up to a certain point better researchers are also better teachers[5]. There is little empirical support for this hypotheses however, and more often than not studies find negative relationship between the two rather than complementarity (Fairweather, 2002; Fox, 1992), even though academics would like the public to believe otherwise. Nevertheless, I tentatively hypothesize that the relationship between teaching and industrial interactions (including research) may be positive in this case for two reasons. First, if teaching and research are indeed integrated, this is more likely to be true in the case of graduate education, where the path of new discoveries from the lab to the classroom is much shorter (for example, a scientists could easily incorporate his recent work into graduate seminars, versus the more time consuming and complicated process of updating the standard undergraduate curriculums). Secondly, if across-the-board positive association between student- and industry related behaviors holds, it may be the case that it could show up in the case of teaching as well. Besides, interactions with industry often enhance curriculum

[5] Teaching and research are seen as mutually reinforcing. From this perspective, the best scholars are the best teachers; the best teacher is a scholar who keeps abreast of the content and methods of a field through continuing involvement in research and who communicates knowledge and enthusiasm for a subject to students. (Fairweather, 1996, p. 100)

development and facilitate the renewal and development of university courses (Stephan, 2001). Therefore, it is plausible to hypothesize that motivated teachers are also motivated researchers who use numerous sources – including interactions with industry – to update and improve their courses.

After a certain threshold however, it is likely that the amount of teaching and interactions with private sector will be negatively related. The negative part of the relationship is quite obvious based on the fact that in typical research extensive universities faculty who can afford to teach less are the ones who bring large government or industrial grants in the department and are able to "buy out" of teaching on a regular basis.

This is a tentative hypothesis in that oftentimes teaching is considered both by institutions and individuals as "necessary evil", or a "minimum justification of existence" for institutions and faculty, or alternatively – some observers are worried that the desire to enhance relationships with industry and to improve teaching are inherently in conflict (Fairweather, 1989). There is no unambiguous evidence that this is the case except one found in the relationships between teaching, research and pay (Fairweather) anecdotal and one from the academic folklore. Moreover, a central assumption of academic life is that research and teaching are (or ideally – should be) correlated (Bowen & Schuster, 1986).

This tentative relationship will not necessarily hold for all types of interactions with industry. As Fairweather (1989) notes "business-university partnerships are not inherently contradictory to academic instructional goals. Depending on the specific nature of the relationship, instructional goals can be supported, harmed, or left undisturbed" (Fairweather, 1989).

H4: *Faculty who place more emphasis on mentoring graduate students are more likely to interact with industry in any capacity.*

Faculty who invest more into mentoring and cultivating students, de-facto also invest in expanding and consolidating their social networks, which is a major precondition for sustaining and expanding their industrial contacts and interactions (Rahm, 1994).Two points underlie this hypothesis. First, faculty who mentor at all in any meaningful fashion will tend to be more experienced senior scholars and thus will have acquired some scientific reputation so that they could actually offer something to their protégés as well as can afford not to worry too much that mentoring may be time taken away from their own reputation building activities. Second, faculty who invest more time in mentoring students invest – purposefully or not – into building an informal network that is usually sustained and utilized upon students' graduation – whether or not these students go into academia or industry. Rahm (1994), for example, reports that 80% of the scientist interacting with industry indicate that former students working in industry sometimes or often contact them regarding firm needs (Rahm, 1994). Therefore, mentoring may be a good approximation for such network building activities and I hypothesize that the greater involvement in mentoring of students, the greater the likelihood that interactions with industry will occur in the future. Lastly, Bozeman and Corley (2004) have already identified that mentoring behaviors of scientists are predicted by stronger industrial orientation (Bozeman & Corley, 2004). Mentoring will not necessarily correlate with all types of industry interactions, however, the above reasons suffice to introduce this general hypothesis.

The above propositions represent the core of my argument about the positive effects of university scientists' involvement with students on these scientists' interactions with the private sector. I will test these hypotheses by means of a set of models, each focusing on a particular dependent variable (e.g. specific type of interactions with industry). This set of models will incorporate the relevant career and institutional controls in order to obtain unbiased estimates of the effects of the student related behaviors on interactions with industry. Before doing so, however, these basic relationships need to be placed in the context of the key variables that affect scientist careers and behaviors.

4. MODEL DEVELOPMENT

The basic proposition of this work is that more intensive involvement with students is a driver of interactions between university scientists and private sector companies. Depicted below is the basic expected directionality and sign of causality, where STUDENTS denotes the full spectrum of student-related behaviors, and INTERACT denotes the spectrum of industry-related behaviors, while e denotes all other influences.

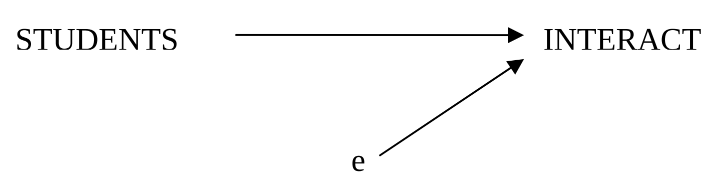

Figure 1. Basic causal model

Such a simple model, of course, is too unrealistic. The faculty interactions with industry and with students will be explained by many additional factors (for now all such other influences are lumped into the error term). Some of the variables that affect probability of engaging in interactions with industry as well as the intensity of such interactions, will almost certainly affect interactions with students. For example, productivity enhances scientists' capacity to interact with the private sector, but it also determines the extent to which a scientist would be able to attract, retain, and support students. On the other hand, his or her ability to recruit students will also have positive impact on his productivity. Not controlling for such influences will produce useless estimates.

The question of non-spurious correlation necessitates careful model development to account for the chief factors that may affect both interactions with students and interactions with industry. Below I identify some of the arguably most relevant variables for the model and discuss them one by one in relation with the other components of the model. Such key variables describing important dimensions of scientists' careers are productivity, collaboration and grants, all of which in accord determine scientists attitudes and behaviors (S. Lee, 2004).

The model does not aim to provide comprehensive explanation of interactions with the private sector, but to allow for isolation of the direct effects that student related behaviors may have on industrial interactions.

Productivity

One important variable likely to influence both interactions with students and interactions with industry is scientist's productivity. Productive scientists are both more capable of attracting and retaining more students and are more capable of entering research interactions with industry. Since productivity is in fact a proxy for scientist's ability to be a "good scientist", measures of productivity are related to almost all variables relevant in modeling scientist behaviors, and this poses several methodological problems but also opportunities.

First, productivity has direct effects on probability of interacting with industry. Productivity is de facto the dominant current explanation of interactions with industry. For example, Blumenthal (1986) reports that university scientists who interact with industry are more productive, devote more time to teaching, and spend more time in professional activities, implying a causal link from industrial involvement to these activities. This specific study concludes with "the most obvious explanation for this observed relation between faculty accomplishments and industry support is that companies selectively support talented and energetic faculty who were already highly productive before they received industry funds" (Blumenthal, Gluck, Louis, Stoto, & Wise, 1986).

Productive scientists will be more likely not only to enter interactions with industry, but also to attract and retain more students. On the other hand, maintaining a pool of students to work with will also have positive effect on scientists productivity (Dundar & Lewis, 1998; Gorman & Scruggs, 1984). Here, however it is not of prime importance to estimate the precise reciprocal relationship between students and productivity[6]. Productivity directly affects interactions with students, directly and indirectly affects interactions with industry. These relationships are depicted below.

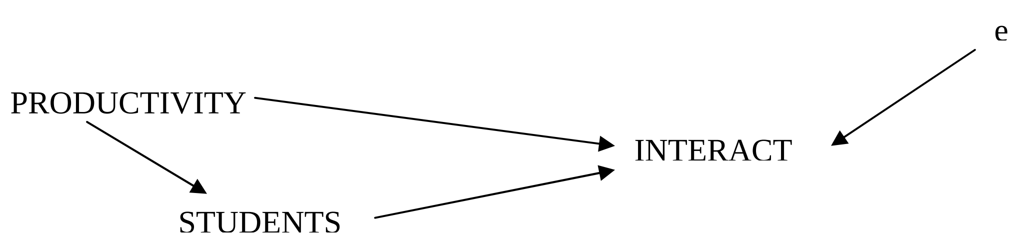

Figure 2. Causal model Step 2 - Productivity

[6] There is little doubt that interactions with students will enhance one's ability to publish more and faster, however, the causal primacy clearly lies in productivity: one needs to already have attained certain level of productivity and prestige in order to be in a position of cultivating and exploiting a pool of students that will in turn enhance his or her productivity.

Productivity is related to students and interactions with industry, as well as with grant activity (next section). Productivity relates to almost all scientific behaviors and activities, however this is no a priori reason to suspect that it will again emerge as the most important explanatory variable in the model. The reason to be suspicious of productivity is that it could be mistaken for a major driver of faculty-industry interactions, which is not necessarily the case. There is little doubt that all other factors equal, more productive scientists will have greater chances of interacting with industry. Such a reasoning is valid, however such a relationships, mistaken for parsimonious explanation is also tautological - better scientists are better scientists in all they do, including interactions with industry. While this has major implications for S&T policy makers and university administrators, this is not an adequate explanation of industrial involvement of individual scientists.

Even if productivity increases the likelihood of industrial interactions, this is a trivial finding that does not generate additional information, but merely registers that 1) even productive scientists apparently have something to gain from industry, 2) that all else equal, industry would prefer to fund or interact with more productive scientists or 3) that in cases of new fields with emerging commercial potential, the industry will simply "hire away" what few experts exist in academia (Stephan, 2001).

Retroactive attribution of interactions with industry to productivity hides the possibility that both are a part of the same concept (e.g. scientific "ability" – a finding confirmed in registering the presence of cross-sectoral accumulative advantage). Such situation, when there is a single dominant explanatory of all observed differences is a true conceptual bottleneck as it by definition prevents the generation of a useful theory of interactions with industry: keeping motivation, financial gains, ability etc. constant, registering that more productive scientists are more likely to interact with industry explains nothing as it shrinks the space between cause and effect so much that the final predictive statement (more productive scientists are more likely to interact with industry) becomes either truism or a circular statement.

In my model productivity, while probably a precondition for industrial interactions, is a variable whose influence is mediated by other variables. In particular, I hypothesize that students will be such mediating variable: in estimating the complete model, whatever effects productivity alone has on industrial interactions, these effects may be diminished after including interactions with students in the model. The hypotheses outlined in the previous chapter, postulate that, at the very least, students are and intervening variable between productivity and industrial interactions. Including productivity in the model will also allow estimating if involvement with students has direct effects in interactions with industry, independent of productivity, collaborations, and grants.

At the aggregate, scientists' productivity is typically measured by the number of peer-reviewed publications in scholarly journals. While such aggregate measure has its limitations, it is an adequate approximation of the ability of individual scientists as it measures the number of successfully produced and accepted by the scientific community knowledge contributions, in the form of articles. Scientists' contributions are multifaceted and heterogeneous. Nevertheless, their primary responsibility is the production of new knowledge in the peer-review controlled outlets of the scientific community. Number of publications - simple counts of the papers written (and published) by the scientists in question – are appropriate measure of scientists' ability to their job of producing new knowledge. The publication – the "paper" – is the tangible product of the research the scientist engage in, and their work is unfinished, and in some ways indeed non-existent, unless they disclose it to the community of peers for review, application and extension in the form of a "paper" (David, 1994). Moreover, the basic counts-of-publications measure of scientific productivity is strongly correlated with measures of quality as measured by peer appraisals (David, 1994). In sum, given the centrality of publications to the reward system in science and the structure of the publication as a document disclosing more or less discrete scientific contribution in one's field, it is justified to follow the numerous studies that have used publication counts as measures of productivity in the present one as well. Specifically, this thesis considers only (unweighted counts of) publications in peer-reviews scientific journals.

Productivity also relates to grants and collaborations, respectively discussed in next sections.

Grants

Procuring grants to conduct research is a prerequisite for sustaining publishing activity, but before that - a function of productivity. Publication productivity is the precondition for acquiring scientific reputation, and as such – the primary explanation of securing grant funding (e.g., Liebert, 1977).

There is also reciprocal relationship – the grants enhance the ability to publish, since they provide the resources without which any further results to publish will have nowhere to come from (Ballou, Mishkind, Mooney, & van Kammen, 2004). As with the possible reciprocal relationship between involvement with students and productivity, in the context of the research questions posed here and due to the peculiarities of the data the exact nature of this reciprocal relationship is not relevant. The data on grants, interactions with students and with industry is cross-sectional. The productivity data however covers scientist's entire career. Current grants cannot predict past productivity, while the opposite is true (Liebert, 1977).

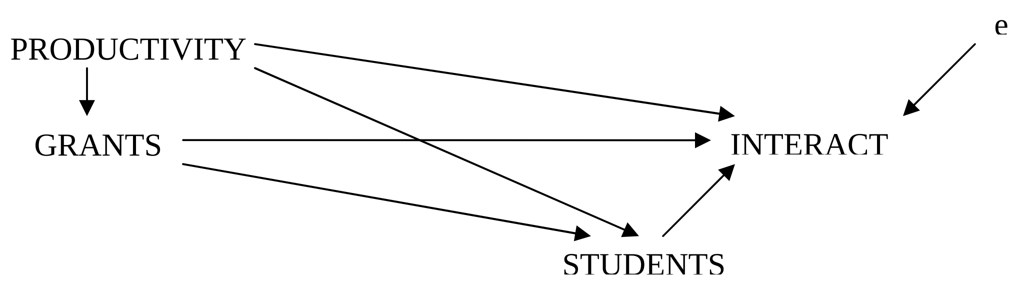

Figure 3. Causal model Step 3 - Grants

Of direct interest is the independent effect of grants (measured as number of grants, government and industry funded, the scientist currently has) on number of students supported and collaborated with, and on interactions with industry. Bozeman and Gaughan (2006) found that grants, especially industrial ones, increase the likelihood of industrial interactions. (They also identifies that grants are antecedent to industrial interactions but not just another type of interaction).

Grants will have direct effect on interactions with students. First, grants are precondition for executing one's research by securing the necessary resources, and students are one of these resources. Since the stipends of students are responsibility of the researcher, most research-related interactions with students are most likely to occur within the context of researcher's grant-funded research. Second, grant-supported research is in general team-based, and some funding agencies explicitly require that the research they fund contain collaboration, education and training components.

I make no particular claims regarding the expected effects of number of grants on involvement with students, except that the relationships will be positive. The data provides information about the number of grants the researcher is currently funded from, by grant source, but not about the magnitude (dollar amount of grants). While grants are a predictor of number of students supported by research assistantships, the grant amount would have been a better predictor of the number of students employed, simply because there is predictable relationship between available funds and students that can be employed. However, in regard to general scientific behaviors, (e.g. collaboration, productivity patterns) the grant amount is not nearly as important as whether or not the researcher has grants at all (Kingsley, Bozeman, & Coker, 1996). Additionally, the variations in grant amounts are perhaps strongly related to the discipline dynamics and resource needs rather than anything else.

In sum, incorporating grants in the model has several methodological implications. First, grants are a major predictor of number of students. The absence of amount data transform the grants variable (in terms of students) into a control variable rather than chief causal driver. As a result, grants will have positive effect on student involvement, however the estimates will hide possibly large variance in these effects.

Second, grants (especially industrial ones) will have strong impact on industrial interactions. Grants are not simply a function of productivity, but the presence of grants, especially external ones, is a good measure of quality of research. In fact, presence of external grants is standard variables in evaluations of the quality and impact scientific research (Melkers, Welch, Kingsley, & Ponomariov, 2006). Grants, therefore, similarly to publications are also a measure of scholarly "ability" – indication of past successes that contribute to ability to enhance other dimensions of research capacity such as involvement with students, as well as have direct impact on interactions with industry.

Controlling for presence and number of grants also helps to address the possibility of reciprocal relationships between interactions with students and interactions with industry. While this thesis claims that the direction of the causality is from interactions with students to interactions with industry, one could claim interactions with industry impact one's interactions with students. However, if any such impact exists, it will occur mostly through grant funding from industry. Bozeman and Gaughan (2006) have established that it is the presence of grants that encourage interactions with industry, but not the other way around. Therefore, given the expected positive effect of industrial grants on student involvement, involvement with students may partially reveal the mechanism through which industrial grants facilitate further industrial interactions.

Besides productivity and students, grants are also related to scientist's collaboration patterns, as discussed in the next section.

Collaborators

Number of scientist's collaborators may be an important factor related to productivity, grants, interactions with students and industry. There is likely a direct effect of scientist's number of collaborators on his or her interactions with industry. First, scientists who collaborate more, all else equal, perhaps exhibit greater general propensity to enter collaborations of any kind, including collaboration with industry as well as collaboration with students.

Second, collaborative research is more likely to be grant funded and experimental, thus more likely to involve both more interactions with students and with industry. Third, scientists who collaborate more are also generally more productive (Price & Beaver, 1966). There is also a reciprocal relationship between collaboration and productivity. On the other hand, productive scientists are also more likely to collaborate (Luukkonen, Persson, & Sivertsen, 1992), but this possibility is not of interest here because of the structure of the data and its peripheral importance for the research questions in the study.

Collaboration, besides being predictor of productivity, is also indicative of a general behavioral pattern of strategically coordinating one's research efforts with others. The dominant motivations behind collaboration are special competences of the co-author, or that the co-author has special data and equipment (Melin, 2000).[7]

Collaboration will also have direct and indirect (through productivity) effects on grants and on student involvement. Scientists who collaborate more are typically more productive, and scientists who are more productive typically enjoy disproportionally large grant support than less productive colleagues. On the other hand, scientists who collaborate more will perhaps support larger network of contacts and will be able to assemble parts of it to pursue further funding opportunities. Scientists may team up to develop grant proposals, which is another scenario of the positive effect of collaboration on grant funding. Besides, scientists who are more inclined to collaborate may enter more

[7] It should be mentioned that beyond the self reported (in surveys) evidence and speculations on the "true" effects of collaboration on productivity, these linkages, albeit plausible are not causally proven. It might well be that collaboration patterns are more heavily determined by the disciplinary and institutional context in which a scientist are working, but not the result of strategic behavior or individual characteristics.

collaborations of any kind, including collaborations with industry. At the same time, scientists who in general collaborate more, are perhaps also more likely to have more student collaborators as well as to support and mentor more students, thus indirectly affecting the interactions with industry.

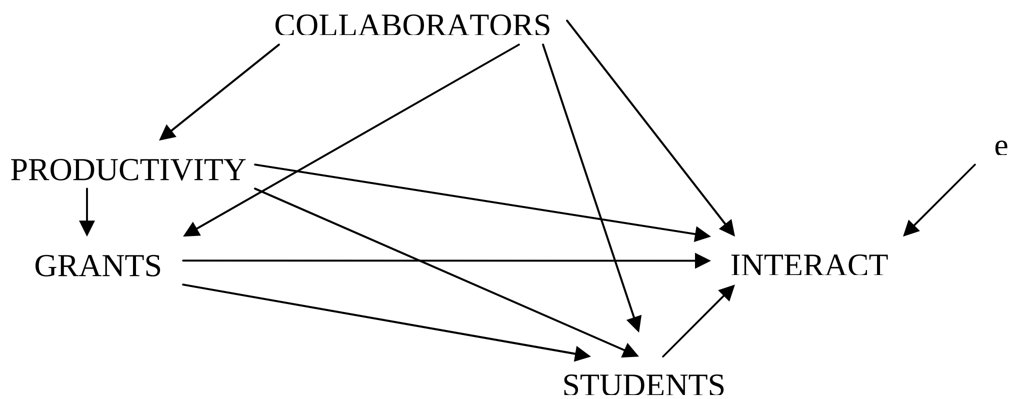

Figure 4. Causal model Step 4 - Collaborators

Control variables

In addition to the above crucial causal drivers behind the relationship of interest, there are several key control variables that intervene in the relationships specified above.

Years since completing the PhD

This variable is preferred instead of biological age as it more accurately captures the "time spent in business" by a university scientist. Some scientists receive their PhDs right away after their BA, while some get their advanced degrees at a substantially later age. Age is a mandatory control since many of scientists' credentials such as productivity, collaborations and ability to secure grant funding evolve and accumulate with age (S. Lee, 2004).

Gender

The role of gender in science is quite mysterious. Some studies argue that women have harder time breaching into male dominated formal academic structures and informal networks (J. R. Cole, 1981). Women collaborate less with collaborators external to their organization and tend to have lower collaboration rates overall (Kyvik & Teigen, 1996). If so, it is plausible to expect negative effects of gender on collaboration, productivity, grants and on student interactions. Some studies have found direct negative impacts of gender on productivity (Fox, 1983). The latter finding however is not stable as some studies find no differences between male and female scientists (Clemente, 1973; J. Cole & Zuckerman, 1984). For the purpose of the current model, I speculate that women will collaborate less (both with peers and with students) and gender will have both direct and indirect negative effects on the probability of interacting with private sector companies and on the intensity of such interactions. Also, since universities have been hiring women at accelerated rate during the last decade or so, it is also plausible that gender will be negatively associated with the probability of being tenured. The intricacies of the impact of gender in scientific careers aside, of primary importance here is that gender will have negative direct and indirect impacts on involvement with students and on involvement with the private sector.

Discipline

Controlling for disciplinary affiliation is critical. As a control variable, disciplinary affiliation "bundles" the structural differences of the working context of scientists and affects almost all of the variables discussed above. Different disciplines have different funding requirements, different structures and processes of scientific investigation, different peer selection processes. Such structural characteristics of disciplines affect proxies of productivity, as different disciplines are characterized with different ease and rate of publishing. For example, experimental scientists collaborate more than theoretical scientists (Gordon, 1980). Applied scientists also collaborate more (Katz & Martin, 1997), since applied research is more interdisciplinary and requires wider range of skills.

Grant funding patterns also vary by discipline. At different points in time some disciplines may simply be originators of "hot topics" that draw the attention of policy makers and funders and thus result in large funding amounts available in a particular field. On the other hand, different disciplines have different resource and equipment requirements – peculiarities usually reflected in the typical grant awards.

Publishing patterns and productivity vary among disciplines. For example, experimental scientists have more publications than theoretical scientists (Hargens, 1981), perhaps a function of the level of routinization in a discipline (Fox, 1983). Number of journals per discipline, journal acceptance rates and co-authorship patterns also vary by field.

Accounting for all such causal influences demands specific measurable contextual discipline-level data (e.g., objective measure of "experimental vs. theoretical", quantitative data on research expenditures, journal acceptance etc.). Such data is however not easily available and the studies mentioned above provide only schematic and partial pictures of the disciplinary impacts on scientific behaviors. Instead, such diverse field effects, albeit not directly measured, are approximated by (and controlled for) by the discipline control variable. As with any control variable, disciplinary affiliation as such cannot be a causal driver behind the other variables in the model, but it is an imperative to control for the above specified relationships in the context of disciplines. I do not specify any causal hypotheses regarding discipline (besides the obvious that scientists from engineering disciplines are more likely to interact with industry). In this interpretation discipline is not a causal driver, but only an approximation of the circumstances that may increase the likelihood of such behavior, being affiliated with specific discipline, albeit crucial, is just a control variable, unless specific discipline level contextual data is used.

Besides a control variable for the general models, discipline is also a variable that will directly impact the number of students with which a scientist interacts. Since different disciplines are characterized with different publishing, collaboration and funding patterns, it is only plausible that they will be characterized with different patterns of student-related behavior, hence the direct causal path from discipline to students in the model. The general expectation is that researchers in more applied disciplines, such as engineering disciplines will interact more intensively with students than colleagues from more theoretical disciplines, such as physics.

The same expectation applies regarding the direct effect of discipline on interactions with industry: scientists from engineering and bio-lie sciences will be disproportionally more likely to interact with industry than scientists from more theoretical disciplines (such as mathematics).

Affiliation with a research center

Affiliation with a research center will be positively correlated with each of the dependent variables. This hypothesis is justified in light of respondents who indicate affiliation with university research centers. Many research centers, such as ERCs, as NSF mandates that these centers collaborate with industry. The primary justification for the creation of research centers is that they provide environment for easier inter-disciplinary and inter-sectoral research – conditions that are not easily satisfied in the traditional academic departments. As a result, scientists affiliated with such centers (not necessarily NSF funded) may be more inclined to collaborate with industry than scientists who are not since in general such boundary-spanning institutions are created to facilitate interdisciplinary and collaborative research – potentially easier to adapt and respond to industry collaboration. Prior study has identified that this may be the case, as well as that center affiliated researchers a re more likely to interact with students in terms of research collaboration and grant support (Gaughan & Bozeman, 2005).

Work experience in industry

Spending part of one's career in industry has interesting mixed effects on his or her scholarly profile. It has been shown to increase the ability to produce commercially relevant outcomes such as patents (Dietz & Bozeman, 2005), but to somewhat negatively affect overall productivity in terms of number of publications (Dietz & Bozeman, 2005; Lin & Bozeman, 2006). However, industry experience also results in greater number of students supported (Lin & Bozeman, 2006). Hence, the expectation that in this model, industry experience of any kind will positively affect interactions with students, as well as the probability and intensity of interactions with industry.

Post-doc

Having had a post-doctoral position will likely have negative effect both on involvement with students and on interactions with industry. One past study have revealed a peculiar effect of post-doctoral positions on future productivity – a negative one (Dietz & Bozeman, 2005). If such effects are indeed robust and present in this data, this negative effect will show up in regard to students as well. On the other hand, in the majority of cases, post-doctoral positions are apprenticeship positions preparing the recent graduate specifically for careers as university researchers, hence perhaps pushing them further away from other applications of their degrees, such as work in industrially relevant research context (Romer, 2000). Lastly, having been in a postdoctoral position perhaps also indicates a self-selection, or particular motivation to pursue a "classic" scientific career versus more diverse or flexible one.

Basic-applied research preferences

Valuation of different types of research may have different effects on interactions with industry and with students. In particular, scientists who devalue more applied research with focus on commercial applications, may be, for example, more likely to work with smaller teams or alone versus scientists who do not place negative valuation on the more applied work. In this study, respondent's subjective judgement of the inherent value of "basic" versus "applied, commercially relevant" research is used to gauge the effect of such valuations on their propensity to enter research contexts that are likely to involve commercially relevant research (e.g. interactions with industry).

Tenure status

There will be differences in regard to interactions with students and with industry depending on the tenure status of scientists. First, tenured scientists are ones who have proven their ability to contribute to their discipline, and have done so through sufficient publications and grants. Hence tenured scientist will be both more productive, will have more grants and will interact with more students relative to their not yet tenured counterparts and as a result – be more likely to enter interactions with industry.

Second implication of the tenured status is the relatively more freedom that tenured scientists may perceive that they have to pursue research-related interactions with industry. More applied research is oftentimes viewed by junior-level scientists as time and effort taken away from potentially academic career-advancing activities such as publishing single-authored papers in the discipline's main journals and as a result these junior level faculty may shy away from industry relevant research (Peters & Etzkowitz, 1990). Industry-related research may not be valued as highly as mainstream fundamental research in the tenure and promotion decisions, hence the expected lesser likelihood of non-tenured scientists to engage in interactions with industry.

Conclusions and complete model

Clearly, other causal paths are possible (and interesting) to consider. However, the model below represent the core of my argument regarding the effect of interactions with students on interactions with industry as placed in the context of the other major factors that may influence both. In short, the model postulates that there is direct effect from interactions with students to interactions with industry, beyond and above the effects of productivity, collaboration behaviors, grant success, discipline, prior industrial or post-doctoral experience, gender, tenure status and characteristics of the institutional environment. While other variables are certainly possible to intervene in these relationships, the variables incorporated in the model will account for most of the variance in the dependent and the endogenous variables.

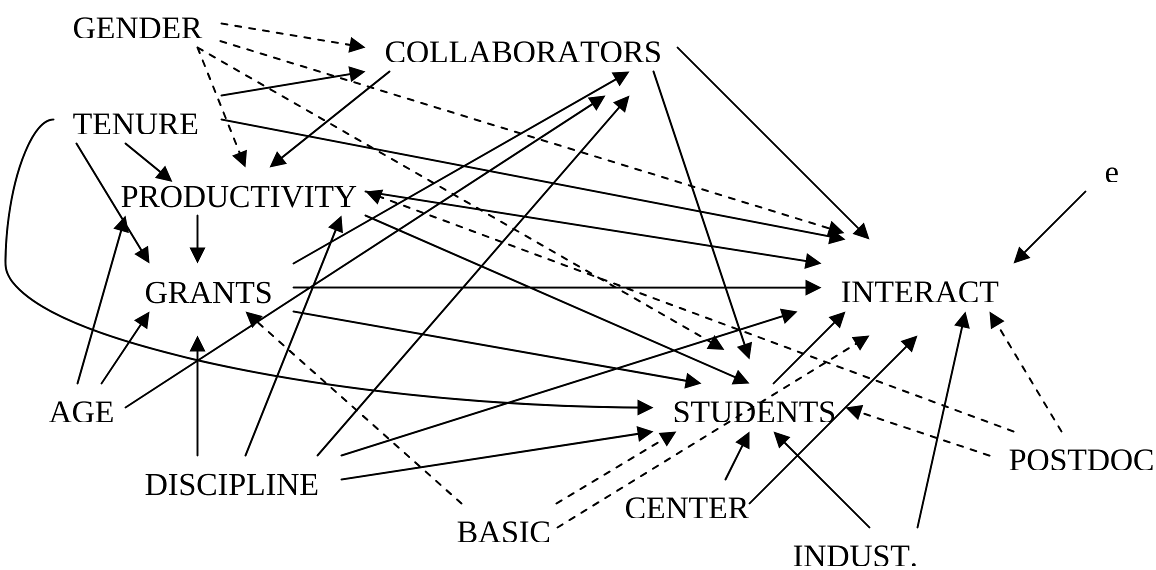

Figure 5. Final causal model

Since involvement with students and some of the crucial career variables are endogenous, the key relationships will be tested by means of the following path models:

(1) $colaborators = \alpha_1 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \zeta_1$

(2) $productivity = \alpha_2 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \beta_1 collaborators + \zeta_2$

$$(3)\quad grants = \alpha_3 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \gamma_7 industrial + \beta_1 collaborators + \beta_2 productivity + \gamma_7 basic + \zeta_3$$

$$(4)\quad students = \alpha_4 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 postdoc + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \gamma_7 industrial + \beta_1 collaborators + \beta_2 productivity + \beta_3 grants + \gamma_7 basic + \gamma_8 center + \zeta_4$$

$$(5)\quad industryitrct = \alpha_5 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \gamma_7 industrial + \beta_1 collaborators + \beta_2 productivity + \beta_3 grants + \gamma_7 basic + \beta_4 students + \zeta_5$$

The analysis that follows will proceed with brief description of the data sources and measurement, descriptive statistics, and step-wise estimation of the path models. These steps are considered in separate chapters.

5. DATA AND METHODS

The variables for this study are derived from two types of data sources. To compile data about individuals' characteristics, career, and productivity paths I use survey data, merged with CV data. The sections below briefly describe the sources of the variables.

2004 RVM survey of US scientists and engineers

The data for this project are collected under the auspices of the 2005 Research Value Mapping Survey of Academic Researchers (RVM 2005), a project funded by the National Science Foundation and U.S. Department of Energy, under the direction of Barry Bozeman, School of Public Policy, Georgia Tech.[8]

The survey targeted tenured and tenure-track university researchers employed in doctorate granting research extensive institutions, as defined by the Carnegie Classification (Carnegie Foundation for the Advancement of Teaching, 2004), though for alternate research purposes some EPSCoR university and HBCU faculty were included. The sample was stratified by university, academic discipline, academic rank, and gender. The resultant sampling frame contained 5,916 individuals. The survey was executed in accordance with Dillman's (2000) "tailored design method.", featuring pre-contact letter, reminder post-cards and follow-up mailings of the survey. The survey was terminated after three mailings, with an overall response rate of thirty seven percent.

After removing from our sample sociologists (to compare engineers to a reference group of non-engineering, "hard" scientists) and faculty employed at EPSCoR

[8] Opinions expressed in this work are not necessarily shared by the RVM 2005 project leadership or the projects' sponsors.

universities and HBCUs (to compare faculty working at Carnegie research extensive universities only), I employ in this study a final N of 1,647 university researchers. The response rate for this subgroup of the survey sample is 37 percent as well.

The non-response bias analysis indicated the following: male university scientists were less likely to respond to the survey, as well university scientists from biology, mathematics, computer engineering and electrical engineering. However, the magnitude of this bias is low (all correlations between stratification variables and non-response are less than 9%).

The wave analysis (simple comparison between the mean values of the variables for respondents who responded in wave 1 versus the ones who responded later (in wave two or three), indicated that people who responded early are no systematically different on any of the variables, with very few exceptions.[9]

The sample for this study was stratified. It targeted the population of tenured or tenure-track scientists employed in the nation's 150 research extensive universities (Carnegie Foundation for the Advancement of Teaching, 2004). Members of the research team compiled a complete list of the population, from which then they drew a sample. First, the research team stratified the population by discipline, and developed 13 sampling

[9] Respondents who responded in later waves were slightly more likely to rank as important reasons to collaborate "desire to work with researchers whose skills complement my own", and the quality of previous collaborations, slightly more likely to indicate more time spent working with researchers in nations other than US and with researchers in other universities, slightly more likely to agree that they enjoy research more than teaching, more likely to allocate more time on research (both related and not related to grants or contracts), less likely to be Asian or black (and more likely to be white), more likely to be US or naturalized US citizen, and more likely to be physicists. These differences are significant at 0.5 level or better, and generally suggest that people who responded later are simply busier, as inferred from some of the variables.

frames[10]. The population lists were compiled on the basis of the university catalogs of the 150 universities in question. Complete population lists were created for the 13 disciplines of interest for the study. Each list was printed, and coded to allow for stratification as follows: 1) stratify by rank (Rank stratification from NSF "Full-time ranked doctoral science and engineering faculty at 4 year colleges and universities, by academic rank, age, sex, race/ethnicity, and disability status: 1995."; 2) Stratify by gender (Select women with certainty, men randomly. (if enough women, they were selected randomly; e.g. in biology). The goal of this development was to achieve samples of 200 male and female scientists from each discipline.

CVs of the 2004 Survey Respondents

Along with completing the questionnaire, the survey respondents were asked to provide their CVs. They were given the option to either send a paper copy back with the survey, provide a link to a web-page from where to download it or send it as an attachment to the project email. The response rate for the CVs (proportion of the actual survey respondents who provided their CVs) was 49.1 percent. Of the 1024 individuals who provided CVs, 393 sent their CVs by emails, 233 provided links for download, and 398 sent back paper CVs along with their surveys. To obtain the remaining CVs, the research team performed web-searches as it was speculated that most academicians have their CVs available online.

The CVs are excellent data source, particularly appropriate for providing relatively standardized and complete information regarding individuals' career experiences (Dietz, Chompalov, Bozeman, Lane, & Park, 2000). For this study, CVs are

[10] The disciplines are the following: Biology, Computer Science, Mathematics, Physics, Earth and Atmospheric Science, Chemistry, Agriculture, Sociology, Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering and Materials Engineering

the source of two variables: the scientist's publication productivity and the presence of industrial experience. Whenever possible, the publication counts were cros-referenced with the Web of Science database.

At the time of the completion of this work, the collection of data for these variables was not entirely completed. Publication numbers were collected for 1008 observations. For the remaining 635 observations publication data was imputed based on a regression model of observed publication data on disciplinary affiliation, gender, career age, postdoctoral status, interaction with industry of any kind, and number of graduate student supported through grants. The imputation procedure was the multiple imputation[11] method as outlined by Royston (Royston, 2004). The missing industry experience values were imputed by means of "hot deck" imputation[12] (Sande, 1983). Since these two variables are of peripheral importance, in all models the results are reported with and without them to establish the sensitivity of the central parameters of interest.

Variables and measurement

The operationalization of the variables discussed in Chapter 4 is provided below, along with the variable names that will be used in the description of results.

Dependent variables: Industrially relevant behaviors

This thesis attempts to assess the effect of students on a broad spectrum of industrially-relevant behaviors, as well as on the general propensity of scientists to

[11] The multiple imputation techniques is based on estimating multiple predicted values of the imputed variable and draws a random sample of these estimates. Multiple imputation is currently considered to be superior to any other imputation method for imputing continuous variables (Royston, 2004)

[12] Hot deck imputation is one of the earliest imputation techniques where values of missing data are extrapolated on the basis of the values of the non-missing variables. This method is especially appropriated for binary or categorical variables (Sande, 1983)

interact with the private sector. As a result, the models will feature dependent variables for each specific industrially relevant behavior, as well as summary measures of industry-related activity.

Measures of specific industry relevant behaviors

The survey asked whether or not the respondents engaged in several specific industry-relevant behaviors during the past 12 months. The variables below are binary, coded 1 if the respondent has engaged in a behavior during the period of interest, zero otherwise:

- INDSCINF (Persons from a private company have asked for information about my research and I have provided it)
- SCINDINF (I contacted persons in industry asking about their research or research interests)
- CONSULT (I served as a formal paid consultant to an industrial firm)
- STUDPLACE (I helped place graduate students or post-docs in industry jobs)
- WORKIND (I worked at a company with which I am an owner, partner or employee)
- PATENTED (I worked directly with industry personnel in work that resulted in a patent or copyright)
- TECHTRSF (I worked directly with industry personnel in an effort to transfer or commercialize technology or applied research
- COAUTHOR (I co-authored a paper with industry personnel that has been published in a journal or refereed proceedings)

General measures of industrial involvement

Besides the above measures of specific interactions with the private sector, I will also utilize more general measures:

- ANYINT (coded 1 if the respondent has been involved in any interaction with a private sector company, zero otherwise)
- INDSCALE (industrial involvement scale, weighted, summarizing the intensity of respondent's involvement with the private sector.)

The weighted industrial involvement scale was developed by Bozeman and Gaughan (2006) on the basis of the same data, in order to facilitate a richer and more parsimonious analysis. The scale is not purely additive because of the large differences in the means and variances for the different types of involvement. As a result, the scale is created on the basis of the distributions of the specific types of interaction with industry and using the inverse percentages as a weight. The inverse weights for all interactions were summed for every individual researcher (based on the behaviors he or she actually engaged in), creating an industrial involvement scale – a single variable summarizing the intensity of the industrial involvement for a scientist relative to the other respondents in the sample. This is a convenient way to allow for parsimonious analysis of the relative intensity of industrial involvement across scientists. The scale is not intended to measure any latent variables, but is simply a device for summarizing the scope of industrial involvement of respondents. Therefore, the estimates for the industrial involvement scale should not be interpreted substantively, but could serve only for relative comparisons of the effects of the independent variables of interest.

Independent variables: student related behaviors

The independent variables for this thesis encompass the full spectrum of scientists' student-related behaviors. This section describes these behaviors in terms of the specific variables that will be used.

- GRANTMA (A count variable, indicating the number of Master's students currently supported through the scientist's grants)
- GRANTPHD (A count variable, indicating the number of PhD students currently supported through the scientist's grants)
- GRANTGRAD (A count variable, indicating the total number of graduate – Master's or PhD – students currently supported through the scientist's grants)
- GRADCOL (A count variable, indicating the total number of graduate students with which the scientist has had research collaborations during the past twelve months
- GRADMENT (A 4-point Likert scale, indicating how important is "Interest in helping graduate students" in the scientist's decisions to collaborate, ranging from 1 (not important at all) to 4 (very important)
- TEACHGRAD (A continuous variable indicating the average number of hours per week that the respondent typically devotes to teaching graduate students, including preparation time and meetings outside class)
- TEACHUGR (A continuous variable indicating the average number of hours per week that the respondent typically devotes to teaching undergraduate students, including preparation time and meetings outside class)

- TOTTEACH (A continuous variable indicating the average number of hours per week that the respondent typically devotes to teaching overall, including preparation time and meetings outside class)
- ADVISE (A continuous variable indicating the average number of hours per week that the respondent typically devotes to advising students about curriculum and job placement)

Control variables

- GENDER (Binary variable coded 1 if the respondent is male, zero if female)
- TENURED (Binary variable coded 1 if the respondent is tenured, zero otherwise)
- CARAGE (Count variable indicating the number of years since the respondent received his or her PhD degree)
- POSTDOC (Binary variable coded 1 if the respondent has held a post-doctoral position in the past, zero otherwise)
- TOTCOL (Count variable indicating the total number of collaborators – not including students – with whom the researcher has had research collaborations in the past twelve months
- PUBSTOT (Total career productivity, measured as total number of publications in peer-reviewed scientific journals. As indicated above, the missing data for this variables is imputed on the basis of multiple imputation with 10 iterations.
- CENTAFF (Binary variable if the respondent is affiliated with university research center, zero otherwise)
- TOTGRANTS (Count variable indicating the total number of grants that the respondent currently is supported by)

- INDGRANTS (Count variable indicating the total number of grants from industrial sources that the respondent currently is supported by)
- GOVGRANTS (Count variable indicating the total number of grants from governmental sources that the respondent is currently supported by)
- BASIC (A 4 point Likert scale indicating whether the respondent agrees with the statement "Worrying about possible commercial applications distracts one from doing good research", where 1 indicates "strongly disagree" and 4 – "strongly agree"
- INDEXP (A binary variable coded 1 if the respondent has had any form of full time industrial employment throughout his or her career, zero otherwise. As indicated earlier, the missing values for this variable were imputed y means of hot deck imputation).
- Discipline: The models will incorporate dummy variables for each of the 13 disciplines, abbreviated as follows:
    - BIOL (Biology, binary variable)
    - CS (Computer science, binary variable)
    - MATH (Mathematics, binary variable)
    - PHYS (Physics, binary variables)
    - EAS (Earth and atmospheric sciences, binary variable)
    - CHEM (Chemistry, binary variable)
    - AGRI (Agriculture, binary variables)
    - CHE (Chemical engineering, binary variable)
    - CE (Civil engineering, binary variable)

- EE (Electrical engineering, binary variable)
- ME (Mechanical engineering, binary variable)
- MTE (Materials engineering, binary variable)

Statistical methods

The proposed analysis is too complicated to allow answering all research questions in a single model. Instead, a sequence of analysis steps will be followed to assess the relationships of interest.

Descriptive analysis

The next chapter will provide an initial overview of the data and will focus on identifying the general between group differences (i.e. scientists who interact with the private sector vs. scientists who do not) in terms of the measures of different student-related behaviors. For some of the key group comparisons I will perform t-tests to gauge whether the observed differences are statistically significant.

Path modeling

Since the model development chapter identified several spurious relationships, it is crucial to identify the causal effects as they emerge through the interactions between the exogenous and intervening variables in the model. To asses these paths and to isolate the direct effects of interests, these causal path will be tested in terms of a set of regressions to gradually build the full model. This estimation is appropriate given the goal of the study, which is to estimate 1) the presence and 2) the relative importance of any effect of student-related behaviors on interactions with industry. The models feature not only continuous, but also binary and count variables for which other estimation techniques would be more appropriate. However, in order to be able to interpret and assess the system of paths, the assumptions that the relationships are linear must be maintained. More importantly, in the case of binary dependent variables this means that linear probability models (versus, for example – logit models) will be estimated. Considering the intent to gauge the relative importance of student –related behaviors rather than specific substantive changes in the marginal probabilities, this linear estimation is also appropriate.

Tobit model of industrial involvement scale

While the primary goal of this study is to assess the relative importance of student related behaviors on industrial activity, the path modeling does not provide estimates that could be interpreted substantively. In order to obtain substantively meaningful estimates for the final model of industrial involvement, tobit model will be utilized to more precisely estimate the effects of the independent variables on the industrial involvement scale. Tobit estimation is the most appropriate in this case because the dependent variable is censored. The OLS estimates will likely understate the positive relationship between the variables while the tobit estimates allow for more precise estimation of the relationships for the non-censored observations, while also estimating the effects of the independent variables on the probability that the dependent variable will have non-zero values.

The next chapter is devoted to the descriptive analysis.

6. DESCRIPTIVE ANALYSIS

General sample characteristics

This chapter provides an overview of the data in general as well as of the general differences in student- and industry-related behaviors of the survey respondents.

This sample is composed of 1643 respondents. Of them, 51% are women, 73% are tenured (respectively, 27% are not tenured but on tenure track). Half of the respondents have held post-doctoral position in the past, and the average time since the completion of their doctoral degree is 16 years. These results are depicted in Table 1 in the appendix.

Student-related characteristics

In terms of grant support of students, it is more common for scientists to support doctoral versus masters' students. Less than the half of the respondents support one or more masters' student through grants, while 66% support one or more doctoral students through grants. The ranges and distributions of the numbers of masters or doctoral students are similar – the highest number of masters' students supported by individual researcher is 20 and the highest number of doctoral students supported is 25. This discrepancy for supporting doctoral students is also revealed in the averages – while on the average respondents in this sample support less than one masters' student, the average number of doctoral students supported is two (Table 2).

Research collaboration with students is somewhat more common than grant support and twice as intensive as grant support: 86% of the scientists have collaborated with one or more graduate students, and the average number of graduate student collaborators is four (Table 2).

For the scientists in the sample, on average, interest in helping graduate students is a consideration when deciding to enter research collaborations: the average score on the four point Likert scale is more than three – a crude evidence of perhaps both academic stewardship towards students as well as some indication of professional exchanges where the student provides labor in exchange of opportunities.

On average, scientists devote sixteen hours per week to teaching, of which about nine hours to undergraduate teaching and about six hours to graduate teaching. This number seems consistent with the hiring expectations in the research universities where appointments are predominantly research based, with some teaching expectation (Table 2). Lastly, scientists devote about two hours a week to advising students about curriculum and job placement.

Industry related behaviors

Interactions with industry are common: 52% of the respondents in the sample have had some kind of interaction with private sector companies during the past twelve months (Table 3). Of course, there is great variation exists regarding what types of interactions scientists typically engage in (and the different types of interactions imply very different demands on scientists' time). The most common type of interaction is being contacted by a private company regarding one's research - 37% (Table 3). This proportion is high but not surprising, considering that contacts with scientists are in fact the second most common source of information after official scientific publications (Gibbons & Johnston, 1974) and considering that some of the interactions do not necessarily tax heavily researcher's time. The next most common interactions are assisting with student placement in industry (25%), proactively seeking contact with private companies and inquiring about their research (19%), and formal paid consulting (18%).

Other common industry-related behaviors are working with industry personnel directly on commercializing technology and co-authoring papers with industry personnel – 15 and 16 percent of the respondents correspondingly. The least common industry-relevant behaviors are having worked with industry on work that has resulted in patents (5%) and working with industry in entrepreneurial capacity as an owner, partner or employee (3%). Obviously, there is a large portfolio of mechanisms of interaction with the private sector ordered on a hypothetical continuum where the most common behaviors are informal ones, followed by more structured interactions (such as co-authorship, and ending with rare, but formal and intensive involvements in entrepreneurial or patenting capacity.

Student involvement of scientists and interactions with industry

Even though numerous interesting between group comparisons can be made, of primary interest here is the involvement with students for the scientists who do and do not interact with industry. Comparing the involvement of faculty in different student related behaviors according to whether or not they had any interaction with industry reveals no statistically significant (t-test results shown in Table 4) differences between these two groups in advising students and teaching graduate students. However, scientists who interact with industry are significantly more likely to be more involved with students in all other capacities: they have more masters' students supported through grants (1.23 vs. 0.51), more doctoral student supported through grants (2.5 vs. 1.5), they collaborate with more students (5.7 vs. 3.4), have higher interest in mentoring students, and devote an one less hour to undergraduate teaching (9.12 vs. 10.34 average hours per week). When looking at the total number of graduate students supported through grants, the scientists who interact with industry support twice as many students than the scientists who do not (3.77 vs. 2).

At the level of this simple comparison, the differences regarding grant support of masters' and doctoral students, research collaboration with students, mentoring orientation towards students are in the hypothesized direction – the scientists who are more involved in this behavior are also the ones who interact with industry. The differences in graduate teaching and student advising, insignificant at this simple comparison are unlikely to surface as statistically significant in any of the further models. The relationship between undergraduate teaching and interactions with industry is opposite to the initial expectation. These initial comparisons are too rudimentary for analysis, but imply that the further pursuit of the hypothesized relationships is legitimate.

Student involvement of scientists by discipline

Discipline is one of the key control variables in the model, and one likely to be associated with major variances in student related behaviors. Figure 6 illustrates the means of master's, doctoral, and total number of graduate students supported through grants, as well as the mean number of students with whom scientists collaborate in research. This figure (as well as appendix Table 5 for the full spectrum of behaviors), show major between-discipline differences.

Scientists in Biology, Mathematics, Physics, Chemistry, on average support almost no master's level students, while supporting considerable numbers of doctoral students. There is a "gap" between doctoral and masters' students supported in all disciplines. Agriculture, Civil and Mechanical engineering are the only disciplines where scientists support roughly the same number of masters' and doctoral students.

The highest levels of research collaboration with students are observed in Computer science, Physics, and the engineering disciplines. In the cases of computer science and engineering disciplines the reason perhaps has to do with the type of research conducted in these disciplines, involving a lot of technical and development work, while in Physics, the complexity of the experimental work demands large number of students.

In all engineering disciplines the average number of graduate students supported through grants is similar – on average, scientists in Chemical, Mechanical, Electrical, Mechanical and Materials engineering support about four students, with materials engineers supporting the most. Computer scientists support one less graduate student on average. Scientists in physical and life sciences support two or less than two graduate students on average.

In all disciplines scientists collaborate with more students than they support through grants. However these gaps are narrower for the engineering disciplines and wider for the physical and life sciences. This implies that the collaboration with students in the engineering disciplines is more likely to occur within the context of grant funded research responsibility of the scientists, while in physical and life sciences the research collaboration is to a greater extend an artifact of the research involvement of students in basic research – some if it large scale and institute or center (but not PI) based, as a part of their training.

These variations in involvement with students indicate that controlling for the effect of disciplinary affiliation is critical.

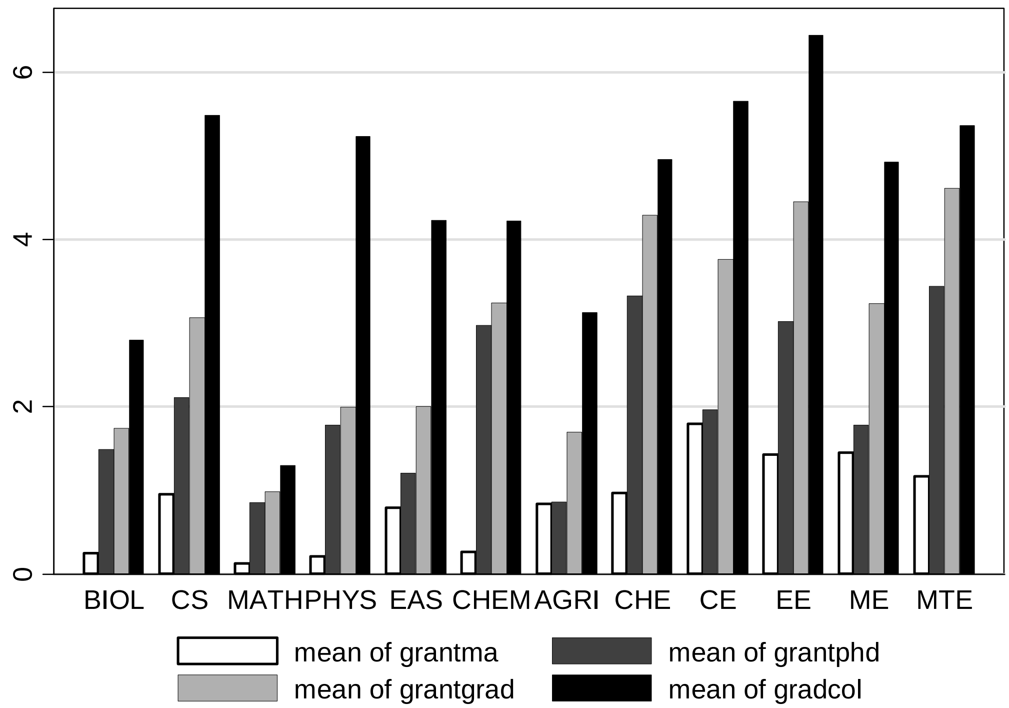

Figure 6. Mean student grant support and collaboration by discipline

Another interesting inter-disciplinary variation in regard to students is the mentoring orientation in Biology and Mathematics. While scientists from all other disciplines, on average, agree or strongly agree that helping graduate students is a consideration in their decisions to collaborate, scientists from Biology and Mathematics on average disagree that this is a consideration in their collaborations. (With this attitude, it is not surprising that scientists in these disciplines also exhibit the lowest levels of collaboration with students.)

Interactions with industry by discipline

Scientists from different disciplines exhibit different propensities to engage in industrially relevant behaviors. Figure 7 shows that scientists from the engineering disciplines are more likely than scientists from physical and life sciences (except agriculture) to interact with the private sector. The greater propensity to interact with the private sector of some disciplines applies to all, not some types of interactions: scientists from the engineering disciplines are more likely to interact with the private sector in all capacities. This is most easily illustrated by comparing the mean scores of the industrial involvement scale by discipline. The distribution of the summary measures of industrial involvement is similar, but not identical to the distribution of key student related behaviors (compare with Figure 6). As such, it supports the intuition that the two types of behaviors may be related but also emphasizes that the relationships will be structurally different in some of the disciplines.

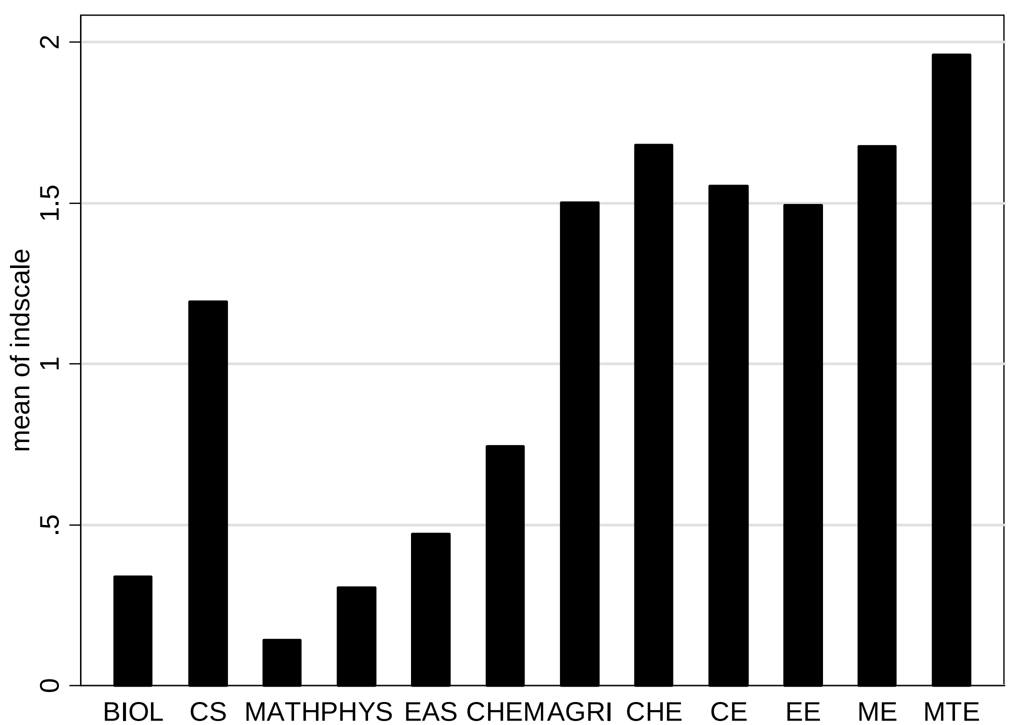

Figure 7. Mean of the industrial involvement scale by discipline (unconditional means)

Even in the disciplines with lowest industrial involvement, some scientists would still interact with the private sector. Do the patterns of these interactions differ from the behaviors typical for the discipline overall? The chart bellows implies that relative intensity of involvement of scientists who actually are involved with the private sector closely resembles the relative differences between disciplines. That is, the disciplinary context determines not only the overall level of involvement with the private sector for scientists in discipline, but is also influences the intensity of involvement for scientists who are involved with private sector companies in some capacity. The single exception from this resemblance is Physics, where scientists who interact with the private sector do so more intensively than implied by the overall industrial involvement of the discipline. In the case of physics however this is not necessarily surprising considering the great number of currents in physics, some of which (typically) with no direct commercial application at this time (e.g. particle or theoretical physics), while other have sustained direct commercial application (e.g. physics of semiconductors).

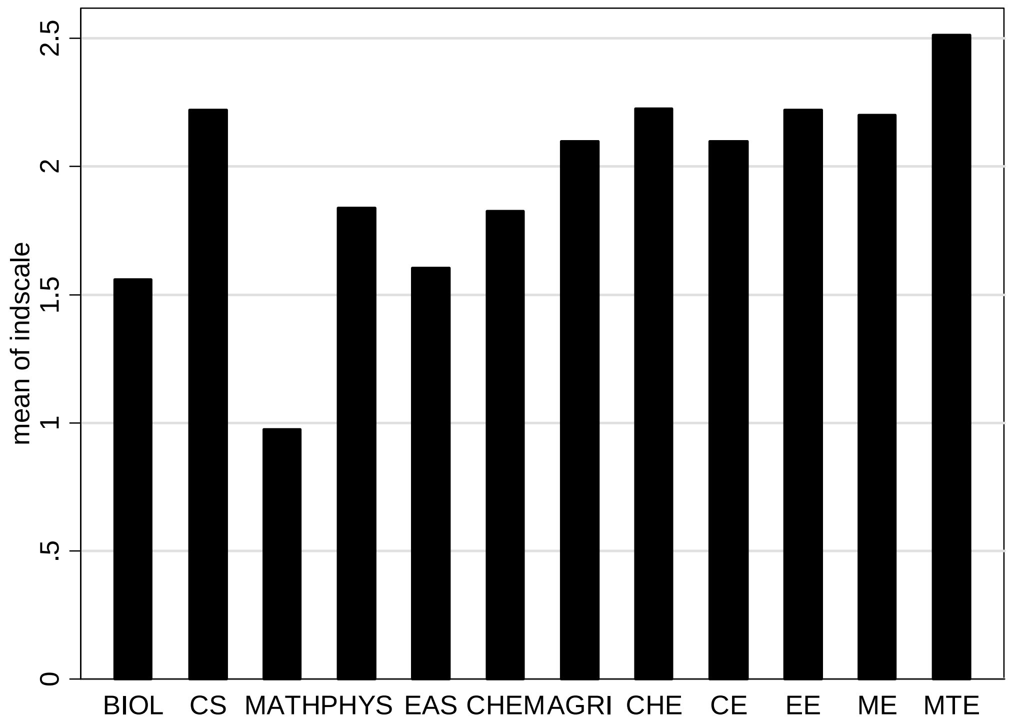

Figure 8. Means of industrial involvement scale by discipline, conditional on having interacted with the private sector

Interactions with students and industry by tenure status

Tenured and non-tenured scientists differ in their student involvement. Tenured scientists spend less time on teaching, but the difference is on average about an hour less, which may simply reflect that tenured scientists are more experienced and efficient teachers that do not need as much preparation.

Tenured scientists are more likely to support more doctoral and masters' students through grants, as well as to collaborate with more students. Tenure and non-tenured scientists spend roughly the same amount of time advising students and do not differ much in their mentoring orientation towards students. These results are depicted on Table 7 in the appendix.

The differences between tenured and non-tenured scientists are more substantial in regard to industry related behaviors (Table 8). Most importantly, while 45% of the non-tenured scientists have had any interaction with the private sector, more than the half (53%) of the tenured scientists have had interactions with private sector companies. Tenured scientists are more likely to have been contacted by private companies regarding their research, but about as likely as the non-tenured scientists to seek out information about the research of industry scientists. Tenured scientists are about twice as likely to have served as formal paid consultants to private sector companies, and twice as likely to have assisted with placement of students in industry jobs. Tenured scientists are also more likely to work directly with private sector personnel on commercializing technologies, as well as to co-author papers with industry scientists.

The brief overview of the general distributions of some key variables of interest showed some initial evidence that most of the hypotheses set forth in Chapter 3 may have some empirical support. The simple descriptive imply that faculty more involved with students in various capacities (especially in terms of grants support, research collaboration and mentoring orientation) are also more involved with industry. This section also showed that various other variables (e.g. discipline, tenure status) structurally possibly affect both interactions with industry and interactions with students. The complex interplay between these and other variables cannot be grasped at the level of simple descriptive statistics. While this chapter set the stage for the test of hypotheses, the next chapters formally assess the hypothesized relationships in the context of the full model set forth in Chapter 4.

7. PREDICTING STUDENT INVOLVEMENT

Chapter 4 indicated that in order to estimate nay direct effects that students may have on interactions with industry, I need to understand the role of students in the context of key indicators of scientific behaviors, most of which will affect both involvement with students and interactions with industry. The key such variables were number of collaborators, publication productivity and grants. Not considering these variables would overstate the hypothesized effects of students. The purpose of this chapter is to isolate the effects of these variables on different student related behaviors and to set the stage for estimating the full model (Chapter 8).

In the path models considered here, collaboration, productivity, grants and the different types of interactions with students are endogenous. The models also utilize a number of exogenous variables most notably discipline, collaborators, postdoctoral and industrial experience, tenure status, career age, basic-applied research preference. The path model follows the set of equations outlined in Chapter 4, and repeated here for convenience.

(1) $colaborators = \alpha_1 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \zeta_1$

(2) $productivity = \alpha_2 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \beta_1 collaborators + \zeta_2$

(3) $grants = \alpha_3 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 discipline + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \gamma_7 industrial + \beta_1 collaborators + \beta_2 productivity + \gamma_7 basic + \zeta_3$

$$(4) \quad students = \alpha_4 + \gamma_1 gender + \gamma_2 tenure + \gamma_3 postdoc + \gamma_4 age + \gamma_5 center + \gamma_6 postdoc + \gamma_7 industrial + \beta_1 collaborators + \beta_2 productivity + \beta_3 grants + \gamma_7 basic + \gamma_8 center + \zeta_4$$

The sections below discuss the determinants of each endogenous variable separately. In all of the models, the reference disciplinary category is Biologists.

Collaboration

Since the motives for collaboration are not of direct importance for this study, I only examine collaboration to the extent it is determined by the exogenous variables in the model. The estimation results are presenter in model 1 in Table 9.

There are no systematic inter-disciplinary differences in typical number of collaborators with two notable exceptions: scientists in Physics and Earth and Atmospheric sciences on average have ten more collaborators than scientists from other disciplines. This is probably an effect of the disproportionally greater resource and equipment requirements in these fields resulting in ever increasing team sizes.

Scientists who are tenured, on average, have four more collaborators than scientists who are not tenured. This is to be expected, as tenure is the formal indication that a scientists has achieved the minimum level of recognition in his or her field through original research, and as the accumulative advantage hypothesis predicts, this is associated with improved reputation which in turn leads to easier access to funding and collaboration opportunities. Tenured scientists are both more sought after collaborators and more able to establish, enter, or maintain collaborative relationships.

The number of collaborators tends to diminish slightly with age, and scientists who are affiliated with research centers on average have four more collaborators. The latter is not surprising as many of these institutions have as one of their primary goals to facilitate and increase collaboration, and as this model implies they might be doing just that.

Productivity

Consistent with most prior studies, collaboration positively affects productivity. The relationship is weakly quadratic (see Table 9). As expected, the relative impact of collaboration is positive and statistically significant. Contrary to some of the findings of prior studies (Dietz & Bozeman, 2005), having held a post-doctoral position has positive impact on productivity. This is perhaps in part explained with the productivity measure used here (total career productivity measured as total number of publications, single or multiple authored by the respondent) and in part with the data (representative sample of US scientists vs. sample of center based scientist in the Dietz and Bozeman study). Postdoctoral positions are typically apprenticeship positions in a research group, and more often than not the post-doctoral researchers will get credit (in terms of co-authorship) even if they did not independently produce a paper. Secondly, especially in some disciplines (e.g. physics, bio-life), post-doctoral positions become the norm rather than the exception, become lengthier in duration and thus probably “absorb” some of the publications that scientists could have – hypothetically – produced in tenure track positions.

Gender and tenure status have has positive effect on productivity of scientists. Male scientists on average have eight more publications and tenured scientists have 13 more publications (model 2, Table 9).

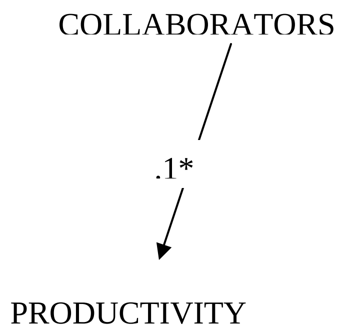

Figure 9. Effect of collaboration on productivity (standardized coefficient)

Grants

The chief determinants of grants funding (besides the inter-disciplinary differences) are collaboration, and productivity, as expected (Table 10). The relative importance of productivity is greater than the one of collaboration. (The relationship between collaboration and productivity and grant funding is certainly more complex than the one utilized in this model and includes reciprocal influences which however are of peripheral importance here and thus are not considered.)

Tenured scientists are also more likely to have more grants, and so are center affiliated scientists. Post-doctoral and industrial experience do not appear to have any statistically significant effect on grants.

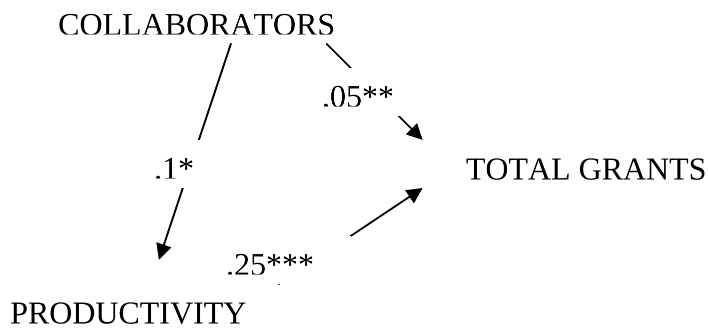

Figure 10. Direct and indirect effects of collaboration and productivity on grants (standardized coefficients)

Does the same dynamics apply to all types of grants (e.g. government versus industry)? Estimating the effects of collaboration and productivity on government and industry grants respectively (Table 10) suggests the answer is no. Collaboration and productivity have no statistically discernible effect on having industrial grants. Tenure status remains a statistically significant predictor of industrial grants, but is a stronger predictor of government grants, rather than industrial grants.

More importantly here, the notable insignificance of productivity and the weaker influence of tenure - perhaps one of the chief marks of success in science, imply that the landscape of competition in academia indeed may be changing. These results suggest that success in securing government funding is dependent on traditional indicators of scholarly success, or reputation. However, such assets seem to be of lesser or no importance in regard to industrial funding. This implies – as this study argues - that the assets that matter in this new context do not always necessarily overlap with what is approximated by productivity and academic rank, thus additional research in determinants of “industrial success” are needed.

Center affiliation positively affects the ability of scientist to get both government and industry grants. As expected, having been a post-doc has somewhat negative effect on industrial grants.

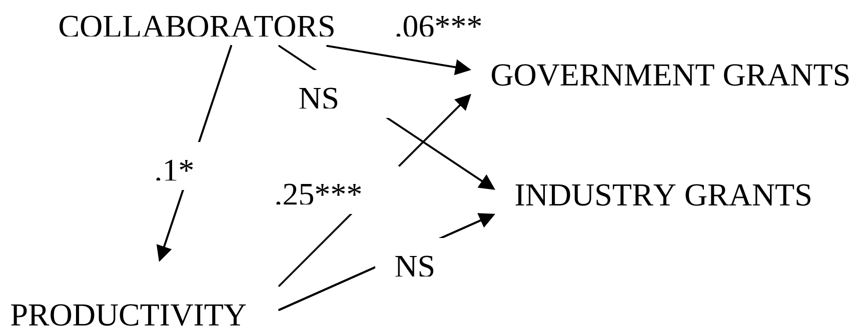

Figure 11. Direct and indirect effects of collaboration and productivity on grants by grants source (standardized coefficients)

After isolating the key interrelationships among the chief endogenous independent variables, now it is time to assess how they impact student related behaviors.

Predicting student involvement

In this study, the above relationships, albeit interesting in their own right are of direct interest only insofar they may spuriously affect the relationship of faculty with students and with industry. To prevent such possibility, it is necessary to decompose these effects. A first step is to estimate the direct effects of the key endogenous variables on student related behaviors. The most notable relationships are discussed below.

Productivity is not related to the time devoted to graduate teaching, but is negatively related to undergraduate teaching. This finding generally reflects the idea the teaching and research are at best unrelated, and at worst – in conflict, which is empirically verified (Fox, 1992). At the graduate level, the lack of statistically significant relationship implies that maybe scientists do not give up (or “buy out”) of teaching in order to pursue research. At the graduate level, through seminars and advanced classes scientists can incorporate their research results most easily into their teaching – if they are equally motivated to be involved both in research and teaching. Undergraduate curriculums however tend to be more standardized and in some cases undergraduate classes are entrusted to more junior faculty (who are thus not yet as productive as their senior colleagues who are in better position to pursue teaching of subjects of genuine interest to them).

Productivity is also positively associated with supporting PhD students through grants, as well as research collaboration with graduate students (Table 11). This is to be expected, as the more productive a scientist is, the more he or she can make of collaboration, and the more others (including students) have reasons to collaborate with him. Additionally, the impact of productivity on number of students supported through grants is not entirely “absorbed” through grants, and persons who are more productive are able to support more students through research, not necessarily grant funded.

Government grants have discernible (more than one hour per week on average) negative effects on total amount of teaching as well as on undergraduate teaching, but have no statistically significant effect on graduate teaching. Industrial grants, on the contrary, have no statistically significant effects on teaching whatsoever. This finding speaks both to higher education researchers concerned with the possibility of industry displacing training activities in universities, and the researchers concerned with the tension between the requirements for research productivity and teaching excellence. To the former, it may indicate that concerns that more intensive industrial involvement will interfere with core activities of universities such as teaching, are not necessarily warranted. To the latter, it may indicate that while the ideal of combining teaching and research might be holding at the graduate level, the reward system in academic departments and in particular the pressures to conduct research and publish (or perish) may be leading to overemphasis on research at the expense of undergraduate teaching and thus may result in the scientists giving up some teaching time for being able to push even harder on their research. This relationship is not surprising considering that many grants allow “buying out” of teaching. This certainly helps to “get the job done” in research, but these results imply that trading off teaching for research is de-facto institutionalized in the current system.

Government grants and productivity are the strongest predictors of the number of PhD students that a scientist supports through his or her grants (Figure 12). Their importance is less pronounced in the case of master’s level students supported through grants (Figure 13). Government grants are a stronger predictor of number of doctoral than number of master’s student supported through grants. The same is true for industrial grants, but the absolute and relative magnitudes of the effects are smaller. Government grants also positively affect research collaboration with students.

The combined effect of productivity and government grants on number of PHD students supported through grants and on number of graduate student collaborators implies that advanced degree students are safely integrated with the research process: if the more productive scientists are the ones who support more students (direct effect), and are also the ones who are much ore likely to have government funding which in turn allows them to support even more students, this implies close connection between the scientist's own research pursuits and his or her ability to extend them into funding entities sanctioned research agenda and his ability to utilize doctoral students as inputs in this self-reinforcing process. This dynamics does not seem to apply for master's student – productivity has weak impact on number of master's students supported through grants, and the effect of government grants is weaker as well (Figure 12 and Figure 13).

Similar dynamics seems to be in place in regard to industry grants as well: industry grants have independent effects on number of doctoral and master's students supported as well as on graduate student collaboration. In addition, unlike government grants, industrial grants are also associated with stronger mentoring orientation of scientists. This is important finding to mention in the context of the forthcoming models as even though industrial grants are weaker predictor of number of students supported or collaborated with, if industrial grants are received in the context of interactions where involvement with students is an expectation, it may be indeed the case – as this model implies – that industrial grants stimulate attitudinal changes such as greater explicit consideration of the mentoring of the students with which the scientist works.

The single strongest predictor of number of students with whom the scientists collaborate in research is the total number of collaborators (not including students). This shows that scientists who collaborate intensively have propensity to enter collaborations in general, collaborations with students included. The next strongest predictor of collaboration with students is the number of government grants – also not surprising given that some funding entities explicitly require the incorporation of training or mentoring components in the research projects of programs they fund.

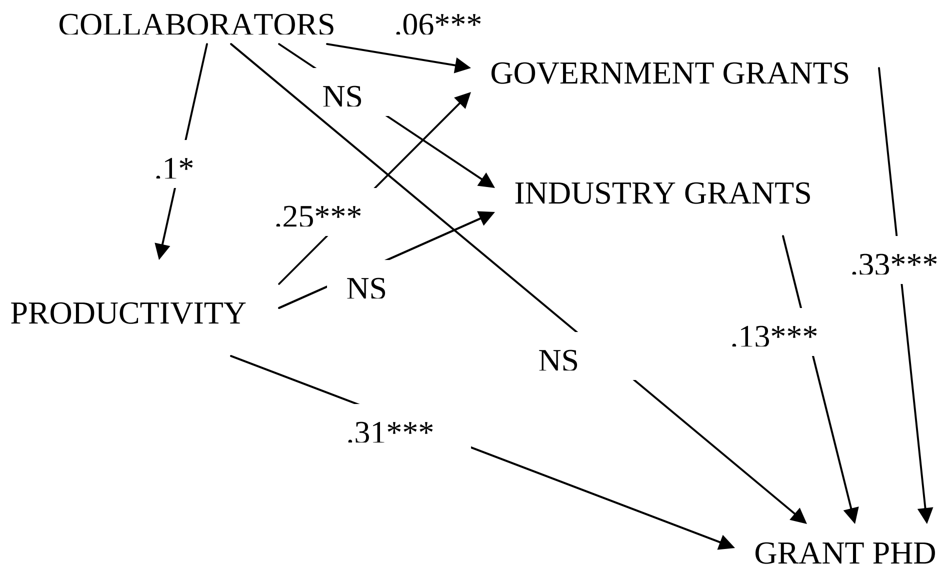

Figure 12. Predictors of number of PhD students supported through grants (standardized coefficients)

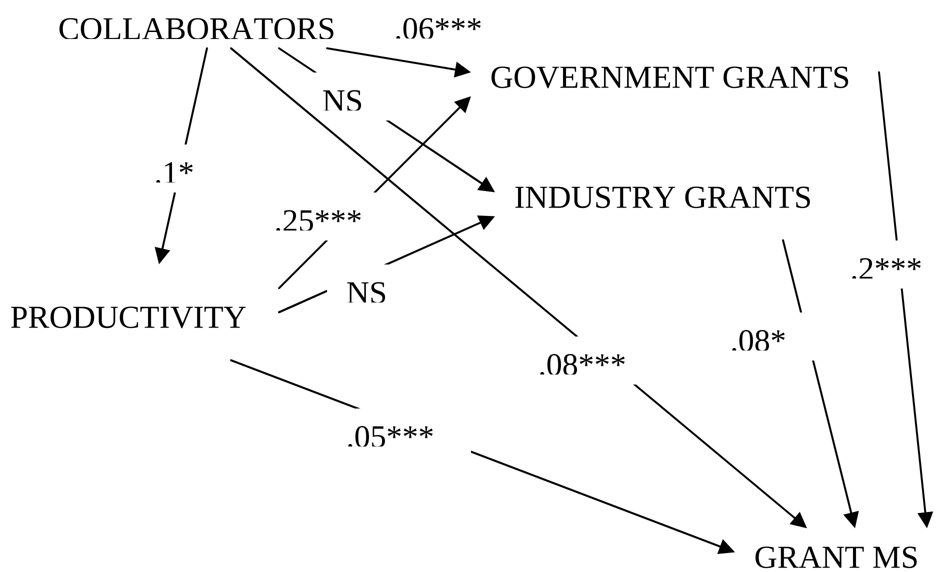

Figure 13. Predictors of number of MS students supported through grants (standardized coefficients)

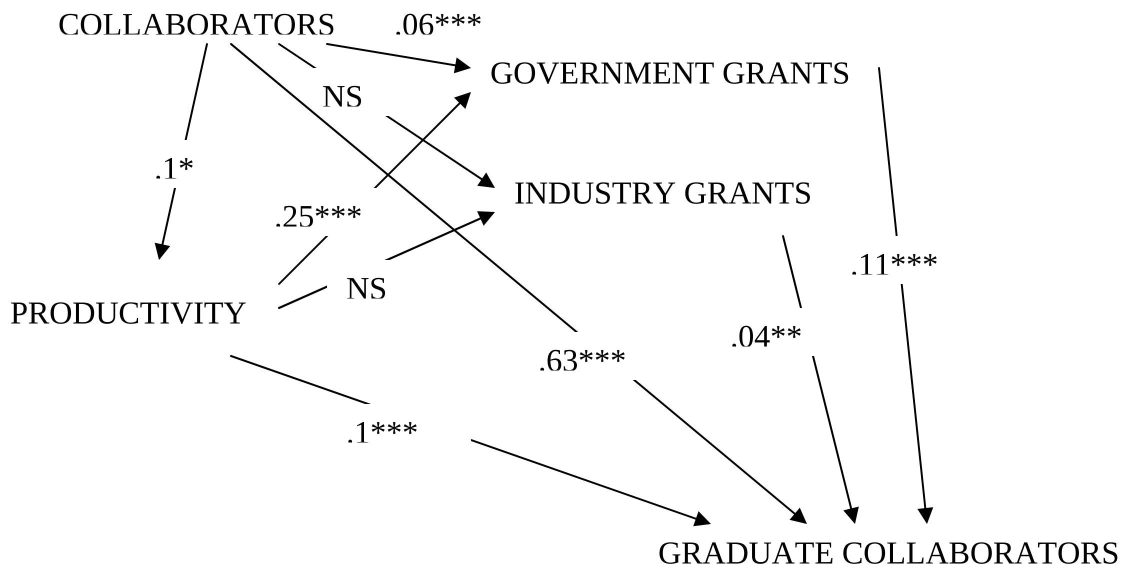

Figure 14. Predictors of graduate student collaborators (standardized coefficients)

It does not seem that mentoring orientation or interest in helping graduate students is affected by the variables in the model. Three notable exceptions include tenure status, industrial grants and gender. Being tenured expectedly increases one's interest in helping graduate students, not least because unless a scientist is tenured, there is probably not too much he or she can offer in terms of mentorship, being a junior scientist himself. The positive impact of industrial funding on mentoring orientation however is more curious. There are numerous plausible ways to interpret this relationship. The argument advanced here privileges one particular possibility namely that industrial funding implies a close relationship with the industrial partners and hence, good knowledge of their needs and concerns. This knowledge, combined with knowledge of the student (employment or training) needs and knowledge of employment or training opportunities that may arise in the private sector, may facilitate both the subjective importance of mentoring students to better navigate these opportunities for their own, the scientists and industry's benefit, as well as may facilitate the undertaking of particular actions (e.g. assisting with student placements).

The negative impact of gender on mentoring orientation has no obvious explanation. Male faculty are less likely to agree that interest in mentoring graduate students is a factor in their decisions to collaborate than their female colleagues. This is curious as in the context of the debate regarding the disadvantage position of women in science one could expect that female scientists, by being subject to more pressures and disadvantages are less likely to invest energy in mentoring students. On the other hand, it may be the case that in fact one structural disadvantage experienced by females is increased teaching and student involvement loads, which may interfere with their research pursuits. However interesting, this relationship is of no central interest for this study.

Total effects of productivity, collaboration and grants on interactions with industry.

A last stepping stone before estimating the real direct effects of involvement with students on interactions with industry is examining the total effects of collaboration, productivity and grants on industrial interactions. Since these variables obviously influence student related behaviors, it is also important to record their total effect on industry related behaviors. These results will be a useful benchmark to compare with the estimates in the final model – after including student related behaviors in the model. The standard coefficients indicating the total effects of these key variables are presented below. The dependent variable is the industrial involvement scale, and the coefficients on productivity and grants reflect the effects after accounting for the effects of collaborators on both of them.

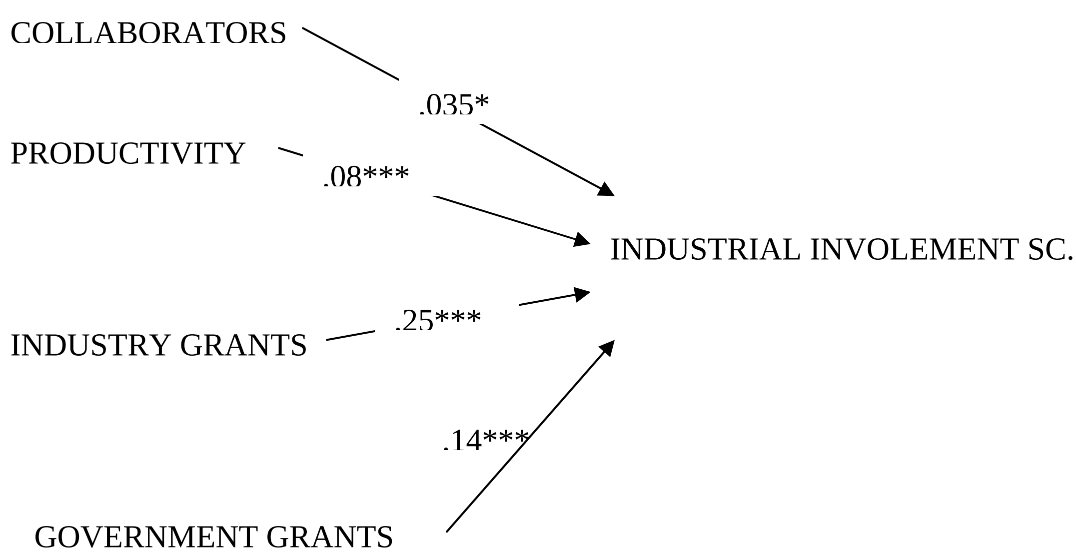

Figure 15. Total effects of collaborators, productivity and grants on industrial interactions (standardized coefficients)

In the context of this study, the total effects represent little interest on their own. The true test of the hypotheses set forth in the previous chapters will come after assessing how these total effects change (if at all) after including the variety of student-related behaviors in the model.

This chapter provided preliminary insights on the possible effects of key career variables on interactions with industry and how students may intervene and modify these relationships. The next chapter is devoted to isolating the specific direct effects that different types of involvement with students may have on interactions with industry.

8. EFFECTS OF STUDENT INVOLVEMENT ON INTERACTIONS WITH INDUSTRY

The previous chapters laid the groundwork for answering the key question of this thesis: whether or not more intensive involvement with students of university scientists is also associated with more intensive interactions with the private sector. The results reported in the previous chapter, albeit not of primary interest for this question, were an essential step towards building an empirical model isolating the unique direct effects that involvement with students might have, outside of any spurious paths from productivity, collaboration or grant support through industry. The sections below present the findings from the full model, starting with the summary measure of the industrial involvement – the industrial involvement scale and then considering the relative strength of the observed effects (if any) on the cases of the specific industry related behaviors.

Table 12 presents the estimates from the full model, featuring all of the student related behaviors. After controlling for productivity, collaboration, grant funding, and the set of control variables, grant support of students, research collaboration with students, and mentoring orientation towards students positively affect interactions with industry. There is no statistically significant relationship between teaching and advising and interactions with industry. This non-finding implies that it may be the case that concerns with industrial activity displacing teaching functions may be unwarranted. The null hypothesis of “no effect” of teaching on industrial interactions cannot be rejected at any conventional significance level. The lack of statistically discernible relationship implies, at the very least, that it is not a common strategy to off-load teaching and advising responsibilities in order to pursue industrial opportunities, as some have feared.

What is the relative strength of the significant effects, and what to the differences mean in the hypotheses set forth in Chapter 3? The figure below presents the standardized coefficients between the different student-related behaviors and the industrial involvement scale

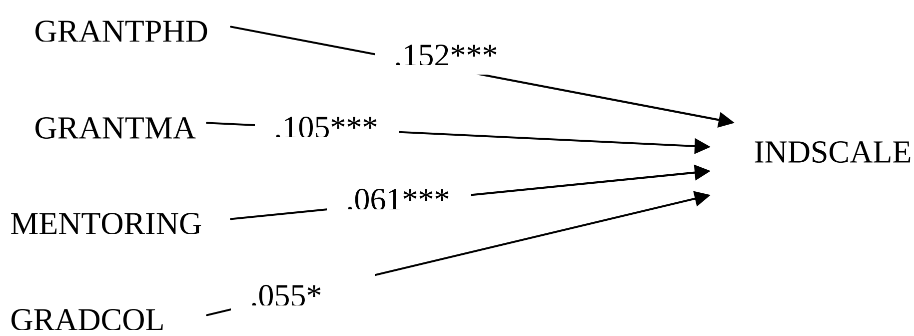

Figure 16. Direct effects of interactions with students on the industrial involvement scale (standardized coefficients)

Supporting students through grants is the type of student interaction most strongly associated with interactions with industry, and the effect of supporting doctoral students is stronger than supporting master's students. These results provide initial support for the core hypotheses of this thesis. There is also a sort of "gradient" effect in the impact of student related behaviors on interactions with industry: the ones that involve the most direct investment from the side of university scientists (e.g. grant support of students) also have the strongest effect on industrial interactions, and the weaker the "investment", the weaker the impact on interactions with industry.

Not only the estimated on key student-related behaviors are positive and statistically significant, but they also weaken or altogether remove the effect of some of the other variables in the model. In particular, the effects of publication productivity and collaboration stop being statistically significant, the total effects of grants are reduced: for government grants from .142 to .059 and for industry grants from .256 to .222. While the reduction in the total effect of industrial grants is negligible, suggesting strong independent effects not shared with the student related behaviors, the effect of government grants is reduced by ~60% suggesting that whatever total effect government grants had, the majority of it is channeled through involvement with students. Before moving to detailed discussion of such results, we should first consider in more detail the particular effects of student related behaviors.

Looking at the standardized coefficients simply shows the direction and relative strength of the expected effects. But what do these effects mean substantively? Table 14 shows the estimates and the marginal effects from a tobit model with the industrial involvement scale as a dependent variable. Tobit estimation is appropriate in this case as the dependent variable contains a large number of observations censored at zero. The table also shows the decomposition of the tobit coefficients.

The student related behaviors affect the probability of an observation having a non-zero value of the industrial involvement scale. In other words, the student related behaviors and attitudes positively affect the probability that a scientist will enter any interaction with industry. The changes in this probability are as follows: supporting one more master's level student through grants increases the probability that a scientist would enter any interaction with industry by 2.1 percentage points. Supporting one more doctoral student through grants increases the probability of entering any interaction with industry by 2.4 percentage points. One point increase in the Likert scale indicating mentoring orientation towards graduate students increases the probability of interacting with industry by 5 percentage points. Collaborating with one more graduate student increases the probability of interacting with industry by a third of a percentage point.

These marginal effects reflect the influences that can be attributed directly to interactions with students, over and above what is spuriously explained by the other variables in the model. Do these effects have any economical significance? Answer to this question makes sense only in comparison with the estimated effects of some of the other variables in the model. For example, looking again at Table 14, we can see that these effects are substantial compared to other important predictors such as gender (increasing the probability of any interaction by 6 percentage points), center affiliation (increasing the probability of any interaction by 8 percentage points), and an additional government grant (increasing the probability of any interaction by 3.8 percentage points.

Obviously, these estimates are not to be used to achieve specific “target probabilities” of interaction with the private sector by urging the faculty to have more students. Nevertheless, these comparisons show that effects are “real”, but not merely statistical artifacts with little substantive significance.

Of all four student related variables, supporting doctoral students seems to have the strongest effect on the probability of interactions with industry as well as on the intensity of these interactions, followed by support of master’s level students, mentoring orientation and collaboration with graduate students. These effects reflect the summary impact of interactions with students on interactions with industry, but hide potentially important information: perhaps interactions with students have different relative importance for the different types of interactions with industry. To estimate such possibility, I also estimate linear probability models for every specific interaction as a dependent variable (Table 13). The chart below (Figure 17) represents the (statistically significant) standardized coefficients to allow better comparisons of the relative impact of students on different types of industrial interactions. There are apparent differences, meaningful in the context of the theory advanced here.

Among all specific industry related behaviors, the strongest association is between the number of PhD students supported through grants on the probability that the scientist has engaged in working directly with industry personnel on commercializing or transferring technology. That this is the most pronounced effect of a student related behavior is important in the context of the hypotheses tested here as it speaks to two of the major arguments for positive relationship between student involvement and industrial interaction. First, numerous studies have shown that in technology transfer activities, the sustained involvement of faculty and students is essential (Poyago-Theotoky, Beath, & Siegel, 2002; Thursby & Thursby, 2004). Second, this type of behavior matches the situation in which the scientist and the industrial partners explore the possible commercial applications of a new invention that is too rudimentary to be "in development" (Randazzese, 1996). Third, the presence of students is the asset that enhances the ability of the scientist to enter this particular type of interaction (relative to his colleagues with the same credentials, but otherwise working with less students) – which indeed is the central proposition of this study.

This is not the only estimate that supports this line of reasoning. The next strongest estimates relate to other behaviors most likely to occur in an "experimentation stage" of technology transfer activities (Randazzese, 1996), namely information exchanges between university scientists and industrial partners. Number of doctoral student supported also strongly relates to information exchanges, both ones initiated by private firms and ones initiated by the scientist, as well as to co-authoring papers with industry personnel. The effect of doctoral students supported through grants is stronger in cases where industry partners have initiated requests, which in the context of the argument of this study I interpret as additional evidence that industrial partners are motivated by the "student capacity" of university scientists and the presence of such capacity is positively related with industrial interactions.

To a slightly lesser extent, number of doctoral students also affects to industrial activity in entrepreneurial capacity and to patenting activity. The role of master's students supported through grants in all these interactions seems to be much smaller, with the exception of patenting, where the effect of master's students is relatively stronger than the one of doctoral students. This is an indirect evidence that in general, interactions with industry are more likely involve relatively advanced research work, not merely routine one (e.g., testing, simulations etc.), that can be easily delegated exclusively to master's level students.

In the case of specific behaviors, collaboration with graduate students is not statistically significant predictor of any industry-related behavior except assisting with placement of graduate students. This directs attention to one component of scientist-student interactions that has been unjustly excluded from the initial hypotheses, namely certain reciprocity of these relationships. While faculty “utilize” students as inputs in the research process for various purposes, students are not completely passive actor in such relationships, but can enter strategic relationships with faculty by providing research assistance (even unfunded) in exchange to collaboration, networking and job opportunities, as implied by these results.

Research collaboration with students had no independent statistically significant effect on any of the other types of interaction with industry, but substantial effect on placement of students in industry jobs. This implies that research collaboration with students is a two way street in which not only the scientist may realize some benefits, but also students. They may seek collaboration opportunities with faculty in order to gain access to these faculty professional networks and use the effort they contribute to the scientist’s research as an entry ticket to some of the opportunities these networks provide. The estimate on graduate student collaboration provides some, albeit of course indirect evidence that such scenario may be in place.

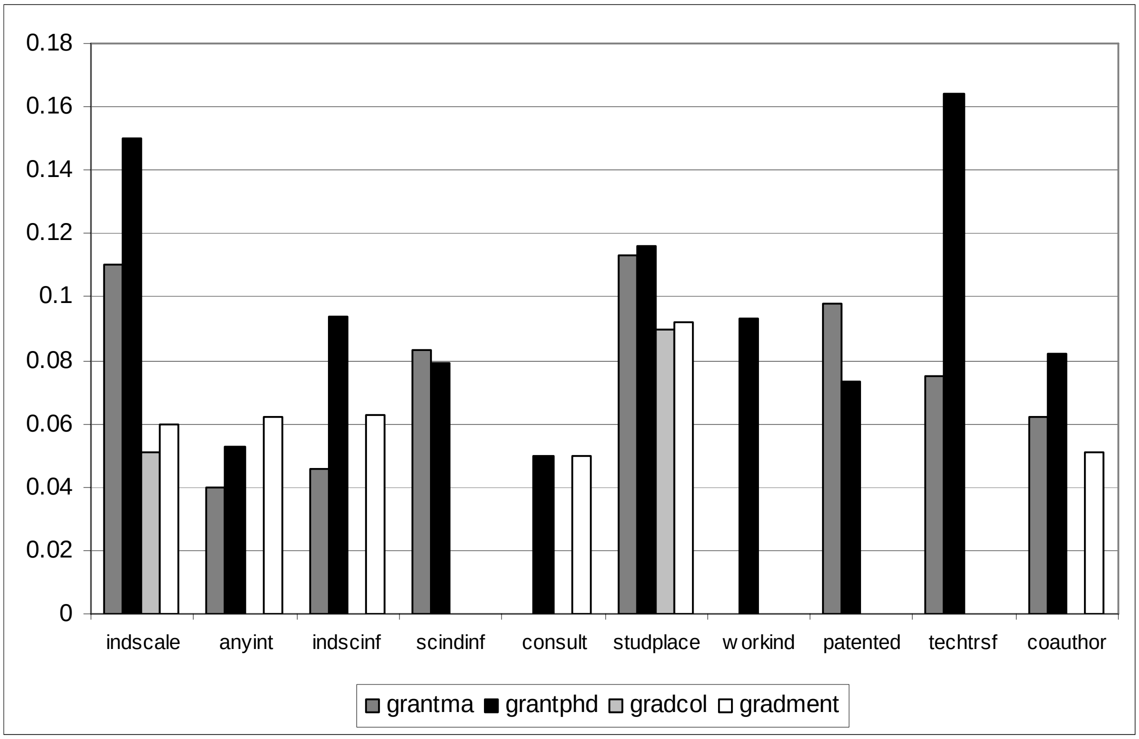

Figure 17. Relative impact of student related behaviors on different types of interactions with industry (standardized coefficients)

Mentoring orientation is an attitude that apparently has differential impacts in regard to specific industry related behaviors. While it is significantly and positively related with the intensity of industrial interactions and the likelihood of entering such interactions, it is not related with scientist’s requests for information from the private sector, working with industry in entrepreneurial capacity, patenting and commercialization and technology transfer efforts. A closer look reveals that the types of interactions that are not related to mentoring orientations also represent working contexts less likely to facilitate mentoring behaviors – it is easier to mentor students in the process of coauthoring papers, guiding them through problem solving activities initiated by industry, advising and assisting them with placement in industry jobs, than in working for industry, patenting efforts, and direct efforts to commercialize technology – where stakes other than research and training come into place.

Consulting activities are the single type of interactions with industry that does not seem to be strongly affected by involvement with students, except for mentoring orientation and grant support of doctoral students. Formal paid consulting is perhaps the least interactive form of interaction possible: regardless of how the consulting assignment occurred, at the end, it boils down to the solution of a specific problem by the university scientist for a fee. It is an application of the toolbox of the discipline mastered by the scientist to industrial problems. This type of interaction does not necessarily involve mutual collaboration and exploration, and more often then not occurs in fixed terms (problem specification, duration, expected deliverables). As such, it does not seem to represent a work context in which there is much room for student involvement. Yet, scientists who exhibit higher mentoring orientation are more likely to enter such interactions, as well as scientist who support more doctoral students. Even though minimal, student involvement still has impact on ability to interact with industry through consulting.

Lastly, it should be noted that not only the involvement with students relates differently to the different types of interaction with industry, but the goodness of fit of the model varies greatly depending on what type of interaction is considered. For the industrial involvement scale the variance explained is substantial (the R-squared coefficient is a respectable .35). Similarly, the fit of the linear probability models explaining information exchanges, student placement, technology transfer or commercialization activities and co-authoring is arguably substantial (Table 13).

However, the explained variance for behaviors such as working in industry in entrepreneurial capacity and patenting is relatively smaller – up to twice as small as the proportion explained for the other types of interactions (Table 13).

The present data allows little more than that to be said about these types of interactions. Incidentally, interactions with industry in entrepreneurial capacity as well as academic patenting are the types of interactions most commonly considered in the technology transfer literature. Yet, they are both least common (only 4% and 6% of the university scientists engage in such behaviors as indicated in Table 3), and least "explainable" in terms of typical academic career variables. These two facts combined imply that the overemphasis on such types of behaviors may not be justified considering their not so often occurrence and relatively random nature. The relatively poor fit of the models implies that it is not common descriptors of university scientists that explain such behaviors, but a set of some other – systematic or random – unknown factors. Whichever the case, this implies that extensive study of this behavior alone is unlikely to render insights regarding larger scale general trends in university-industry interactions at the individual level, unless other industry-related behaviors are considered as well.

Other effects

Several other factors affecting interactions with industry, albeit of peripheral interest to this study deserve mention and are interesting in their own right. First, personal research preferences play role in interactions with industry: scientists who devalue applied research and equate basic research with "good" research are both less likely to enter any interactions with industry, and even if they do, less likely to intensively collaborate with the private sector. It should be noted however that such preferences do not have any statistically significant effects on any of the student-related variables (Table 11).

Having bee in a post-doctoral position also decreases the probability of entering any interaction with industry (by 9.8 percentage points), and the intensity of such interactions for the scientists who have had some interaction with the private sector. Having been in a post-doctoral position however also does not impact any of the student-related behaviors, except for a negative statistically significant effect on number of master's students supported through grants.

Center affiliation is positively associated with the interactions with the private sector – it both increases the probability of entering such interactions (by 8.6 percentage points) and the intensity of the industrial interactions. Center affiliation is also positively associated with supporting doctoral students through grants, and negatively associated with teaching (implying "teaching buyouts"). The total effect of center affiliation decreases by about 30% after including student-related variables (from .095 to .07), thus implying that at least a portion of the positive effect of center affiliation on industrial interactions is due to student interactions.

Summary

Interactions with student via grant support, research collaboration and the presence of mentoring orientation towards students in university scientists have positive independent direct effects on the likelihood of entering interactions with industry and increase the intensity of such interactions. Teaching and advising of students have no statistically discernible effects interactions with industry. Interactions with students are accountable for considerable portions of the total positive effect of government grant funding on interactions with industry, and seem to be mediating variables between publication productivity and collaboration, and interactions with industry as upon including student related variables in the model, collaboration and productivity stop being statistically significant.

These direct effects result support four out of the initial six hypotheses of this work. While the research questions attempted to estimate the effects of the full spectrum of student-related behaviors, the ones that surfaced as present and significant at the end of the analysis are the ones most closely related to the theoretical argument advanced here. After examining the effects of institutional characteristics (In Chapter 7), the discussion of these findings in the context of the theories that informed this analysis is the subject of Chapter 8.

9. DISCUSSION

The estimated positive direct effects of key student related behaviors and attitudes (e.g. grant support, collaboration, and mentoring orientation) have several theoretical and policy implications.[13] The theoretical implications discussed in this chapter directly pertain to 1) the discussions of the possible consequences of the closer integration between the academic and industrial sectors; 2) the implications of the findings for conceptualizing scientific work and careers and 3) to theoretical conceptualizations of the technology transfer processes between academia and industry at the individual level.

Industry and academia – concerns over interference

The concern over the possible interferences of industry into academia is perhaps at least as old as the explicit policy attempts to bridge the gaps between the two that have arguably intensified since the 1970s. Some researchers were worried that the incentive structures and organizational structures of both were incompatible (Campbell & Slaughter, 1999; Johns, Barnes, & Florencio, 2003) and the increased industrial funding and involvement in university research would sooner or later have detrimental effect on core academic functions and values (David, 2004). One specific area of major concern concerns the radical differences in intellectual property regimes (David, 2004). While in science openness and prompt publication of all new discoveries is the norm, industrial interests are better served by secrecy and protection of intellectual property. In fact, the need for secrecy is so strong, that societal mechanisms such as the patent system were

[13] While theoretical and policy implications easily overlap, they are considered in separate chapters, The current chapter is devoted to theoretical implications, and the next one discusses implications for policy

devised to stimulate disclosure of inventive information in exchange of temporary monopoly.

Others were concerned that “academic capitalism” can radically alter the values of scientists and further displace the core functions of universities. Of particular concern is the possibility of scientists, always looking for ways to fund their research would become de facto servants to industrial interests, doing what they have to get the research dollars, even if this means neglecting some other roles such as teaching and training (Anderson, 2001).

The findings reported in this work speak predominantly to the latter group. The estimated positive direct effects of interactions with students not only do not confirm these fears, but imply that different dynamics may be in place. First and foremost, the models estimated imply that scientists do not give up essential activities in order to be able to pursue industrial opportunities. If anything, their ability to excel in such activities, relative to their peers enhances, but does not diminish their ability to interact with industry.

Non-findings in general are not meaningful, but in this case the absence of statistically recognizable relationship[14] between teaching and advising activities and interactions with industry also speaks to the above concerns. Teaching involvement (as measured through time devoted to in-class teaching and preparation), is one of the easiest things to downplay in one’s workweek (up to the obvious limitations of scheduled in-class time) in order to devote as much time as possible to research, and especially to industrially relevant research. Yet the results reported here do not support such reasoning: there is no significant relationship between teaching and industry interactions. Even the

[14] $p>0.6$

most formal commitment to industry – in the form of receiving industrial grants, presumably extended in exchange of expected effort and deliverables – do not seem to affect the level of teaching and advising involvement of university scientists.

More important here however are the "real" findings, namely the direct positive effects of grant support of students, research collaboration with students and mentoring orientation on probability of entering industrial interactions and on the intensity of such interactions. These student interactions positively affect interactions with industry over and above any direct and spurious effects of key scientists' characteristics such as academic rank, age, collaborations, publication productivity and grant funding.

But why and how exactly interactions with students enhance interactions with industry? Looking back at the theory of accumulative advantage and to a general theory of university-industry technology transfer helps elucidate a plausible scenario.

Assets and rewards in academic careers

The basic justification of the hypotheses tested in this thesis was that certain dimensions of the complex role of being a scientists (for example, training and support of students) may be valued and rewarded by the industrial sector at least as much, if not more, as other measures of scholarly success, such as publication productivity. This hypothesis was informed by the phenomenon of differential returns and unequal distribution of assets and outputs in science. The basic mechanism is that some dimensions of the scientific outputs are simply valued and rewarded more than others. Traditionally, this has been the publication productivity 0 the single most important determinant of success in science. However, the arena of academic competition is changing with the increased emphasis on industrial interactions, and one of the consequences of this changed competitive landscape may be increased valuation of other aspects of the scientific role.

The increased integration of public and private science orientations on US campuses may have indeed “fractured the status-based stratification order governing achievement in the public science arena and altered the conditions for competition” (Owen-Smith, 2003, p. 4). One consequence of such process would be the enhanced ability of scientists to undertake different paths to academic success – paths that do not diminish or replace the importance of scholarly productivity, but provide more diverse ways to attain it.

By and large production and publication of knowledge is arguably the most important role of scientists. Nowadays publication productivity is still the primary proxy of scientific ability, and the single most important indicator of scientific achievement. However, it is no longer the only one. Other dimensions of the scientific role have gained more attention and valued relatively more than previously. The social context in which science is embedded has changed appreciably. The most notable changes include the introduction of numerous non-scientific stakeholders in the process of managing science, and more importantly – change in the expected deliverables, nowadays expected to include appreciable impacts, or at least relevance (e.g. contribution to competitiveness and private sector innovation). Combined, these trends have altered the landscape of academic competition (for credit, but also let’s not forget funds). Being commercially successful is not anathema but a major achievement. New research institutions have emerged that place more complex demands on scientists, and sometimes scientists need to compete for funds with institutions emphasizing commercially relevant research.

In this context, roles previously non-essential for success in science (albeit formally required), may have become important in new ways for success in this new environment. Considering that training and research are closely integrated in the system of higher education, the importance of students may have risen to occupy the place not of mere raw material for academic careers (any leftovers or “not good enough”s of which used by industry), but the place of a direct input to private sector innovation, sought directly from the universities in the process of interactions with university scientists, but not something simply purchased on the labor market.

Obviously, the mere quantity of students one supports or collaborates with cannot “cause” interactions with industry. Let’s perform a thought experiment. What is left over from a university industry interaction at the individual level if we keep all else equal, but subtract any student interaction? We’ll be left with a university scientist and industrial partners presumably sharing a common interest. We will have some general understanding that the research expectations of both parties complement each other. If all of these conditions are present, however, but there are no students in the mix, nothing will happen. There may be occasional conference contact, phone call, but no sustained interaction. The institutional orders and working contexts in academia and industry, and there is little to bridge them. No self-respecting scientist would “do industry’s work” – in which case his scientific credentials could indeed suffer, and no industrial partners could, or could afford to gain a true entry point to the research performed by the scientist except in highly formalized settings such as contract research or in research centers.

The theory advanced in this thesis, and backed up by the results, implies that the presence of students may be a bridging component helping establish, maintain and expand university-industry collaborations at the individual level. In this role, students become an essential component of the technology transfer processes and an important factor that deserves careful conceptualization in the research on UIRs. Interactions between university scientists and industry are often organized around the mutual exploration of a rudimentary finding which may or may not be commercialisable. The industrial and university partners participate in this exploration or experimentation stage (Poyago-Theotoky, Beath, & Siegel, 2002; Randazzese, 1996) to get a better grip of the problem and assess its commercial potential or to gain insights for new research. This work often involves on-site or personal consultations, a lot of experimentation, testing, and simulations: work too advanced to be entrusted to ad hoc technicians, but too mundane and too much for a scientist to accomplish himself. The presence of students constitutes a dimension of scientists' capacity to identify, act upon and exploit problems of potential interest to industry, and to explore them in collaborative setting.

The presence of students also may be an independent motivation for industrial partners to pursue such interactions by 1) being qualified personnel to accomplish the exploratory work characterizing such arrangements and 2) by being immediate and future capital gains for the participating firm. Even interactions with no particular deliverable may be beneficial for industry if what the firm gets is access to competent potential employees that can be courted and hired. While speculations regarding such scenario have been popping occasionally in studies of technology transfer (Behrens & Gray, 2001; Randazzese, 1996; Slaughter, Campbell, Holleman, & Morgan, 2002), quantitative test of the plausibility of this scenario has not been accomplished to date. This study partially fills this void in the literature.

Since students are a research input in scientists' own research, the sheer quantity of students funded through scientists; grants or with whom the scientist collaborates will have impact on the probability and intensity of interactions with industry. While most scientists have some students in their supervision with whom they partner in the process of their research, scientists with – literally – more students will be better (relative to colleagues with same credentials otherwise but less involved with students) positioned both to accomplish their scholarly goals and also to be able to afford to look for problems and opportunities such as the ones provided by interactions with industrial partners.

Since the landscape of academic competition has evolved in realms beyond the "ivory tower" regulated exclusively by the peer review process to include capacity of demonstrating appreciable effects of one's research – including commercial success, or sustained ability to make contributions to such success – the role of the relevant dimensions of scholarly ability have evolved as well. This thesis argued that involvement with students, while as old as the university system itself, is a dimension of the scientists' research capacity that is suited for competing in an arena characterized with increased acknowledgement and pursuit of research interactions with industry. The scientist better endowed with such capacity will have greater chances of recognizing and acting upon industrial opportunities as well as will be more sought after by industrial partners. These interactions may result in further commitments, including grant funding and contract research, resulting in opportunities to utilize and train more and more students, thus perpetuating the cycle.

These findings perhaps tell us something about the organization of science in general. It is unlikely that intensive involvement of scientists with students enhances these scientists' interactions with the private sector and nothing else. Perhaps the interactions with students are a feature of the scholarly life that results in better science in general. The contemporary higher education system, especially its US version, is fairly formalized and attempts to standardize and production of scientists on the basis of standardized curriculums, course sequences, exams, etc. These are very important educational innovations, which however, should not be thought of as replacements of the close interactions between scientists and students – an absolutely essential feature of advanced education. One broad implication of my findings is that industry and academia may be indeed connected at a fundamental level – at the level of advancing science as a process of joint discovery of mentors and their students. In this process, industry maybe is not an intruder, but one more arena where this process of discovery could take place. If so, the connections between science and industrial innovation are already more intimate than implied by merely registering that industry does utilize scientific knowledge.

If a common scenario of university-industry interaction involves exploratory work where university and industry partners complement their interest in a phenomena by exploring its scholarly and commercial implications in a setting where students play vital role, then it is plausible that students represent a dimension of scientists' research capacity suited for effectively navigating in such circumstances, by serving the goals both of the scientist and the industrial partner. If such mechanism is in place, one indication of its presence would be a positive relationship between involvement with students and involvement with industry. The results reported in this thesis suggest that such direct relationship is plausible. This of course does not make the claim suggested here "true", it only fails to refute it just yet. Nevertheless, this is a reason for optimism, not methodological despair. In the Popperian conceptualization of scientific advancement no scientific statement could be assumed true with certainty, it can only be falsified with certainty. The present results fail to falsify the claims made here, which means that they are conditionally plausible until further tests demonstrate results contrary to predictions or derive better alternative explanations.

10. POLICY IMPLICATIONS

Similar to the problem of complementarity versus competition between research and teaching (Fox, 1992), the problem of mutuality or conflict between core university functions (especially training) and interactions with industry, has organizational and policy implications. These issues have become increasingly controversial, as whether or not educational and research activities, and interactions with industry is by no means obvious, well understood and certainly not resolved.

The main result of this thesis provides incremental contribution towards an understanding of university-industry interactions as activities that complement each other, but not necessarily interfere with each other. Since the question of how to reorganize and adjust the university system to better integrate it with the increasing knowledge needs and problems of the industrial innovation, this finding provides some additional policy guidelines on how to better pursue such a goal.

One more tool in the university-industry policy toolbox

The main result of this thesis, with both theoretical and policy implications, is the enhanced understanding of the factors that drive university-industry interactions at the individual level. This thesis assesses the relative importance of arguably the key variables describing scientist's behaviors. The results shown here generally demonstrate that the same behaviors that are usually associated with scholarly success (such as productivity, grant funding, collaboration) are also associated with engaging with the private sector. More importantly, the results imply that one particular, and previously neglected component of scientists behavior – the interactions with students – in itself is an important catalyst of interactions with industry. Interactions with students have direct effects on interactions with industry, and mediate the effects of productivity and collaboration and government funding.

Such finding regarding the nature of university-industry interactions in itself provides a possible tool for interventions and it can have multiple uses. This new understanding leads to multiple possible policy implications, and can inform policy relating to university-industry relations and higher education policy in general. These implications are enumerated below.

Rethinking the emphases in S&T policy legislation

The possible contributions of the findings of the study to the recent S&T policy debates are best illustrated by linking these results to the current practice in the field. What existing policies and programs exist to facilitate and intensify the interactions of university scientists with the industry? In what ways, if any, do they relate to or consider the students in university-industry interactions? Most notable among the US national level policies is the sequence of technology transfer related legislation enacted in the last twenty years.[15]

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[15] These landmark laws include the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480) which mandated that federal labs set aside technology transfer budgets and establish procedures so that external parties could access lab technology; the Bayh-Dole Act of 1980 (P.L. 96-517) which allowed universities to obtain titles to patents developed with federal funds; the Small Business Innovation Development Act of 1982 (P.L. 97-219) which required agencies to provide special funds for small business R&D related to agencies missions; the Federal Technology Transfer Act of 1986 (P.L. 99-502), which required that technology transfer activities are considered a responsibility of federal lab employees, and used in employee evaluations. This law also allowed federal laboratories to enter CRADAs as well as to negotiate licensing arrangements for laboratory inventions. Other legally sanctioned policies include Executive Order 12591 of 1987, which required laboratories to identify and encourage individuals to serve as liaisons between federal labs, universities and the private sector. Another important law is the Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418), which emphasized the need for public-private cooperation in realizing the benefits of R&D and established centers for transferring manufacturing technology as well as the Industrial Extension Services. The National Competitiveness Technology Transfer Act of 1989 (P.L. 101-189) extended to the government owned and contractor operated laboratories the same ability to enter CRADAs and provided additional provisions for protection of

This legislation, albeit seemingly diverse and all-encompassing, is in fact characterized with common underlying logic and a handful of very specialized goals and assumptions. In particular, all these laws seek to increase the rate of transfer of academic research advances to industry and to facilitate the application of these research advances by firms as part of broader efforts to improve national economic performance. Most of these policies "focus on the codification of property rights to inventions, and rarely address the broader matrix of university-industry relationships that span a broad range of activities and outputs." (D. Mowery & Sampat, 2006, p. 210).

This diagnosis is troubling considering the broad spectrum of university industry interactions. One particular component of this broader matrix – the training and educational component in technology transfer activities is almost entirely missing from this legislation.[16] This does not need to be the case. After all, the behaviors and incentives for the academic institutions are more feasible to influence by the government, as opposed to less understood behaviors such as informal interactions between university and academia, which could hardly be legally sanctioned.

The main policy implication of this work is that national science policy should worry less about transferring deliverables to industry, and more about strengthening the educational system. The results reported here further indicated that "deliverables"

intellectual property. The American Technology Preeminence Act of 1991 (P.L. 102-245) further extended and formalized the guidelines for protecting intellectual property and sanctioned its exchange among CRADA participants. These are the key laws on the topic, Other laws or amendments of these laws have been passed in the 1990s. They include the National Department of Defense Authorization Act for 1994, (P.L. 103-160), National Technology Transfer and Advancement Act of 1995, (P.L. 104-113), Technology Transfer Commercialization Act of 2000, (P.L. 106-404)

[16] For example, the keyword "students" is found in total of only 19 instances and the keyword "education" - in 188 instances - under titles 15 (Commerce and Trade) and 35 (patents) of the US code, which contain the technology transfer and patent legislation sections respectively. These are surprisingly low number of mentions, considering that these are the results for the entire titles, not just for the specific chapters pertaining to technology innovation (Title 15, Chapter 63) or patenting (Title 35, Chapter 43).

behaviors, such as patenting and entrepreneurship are not well explained with traditional measures of scholarly success, which implies that over emphasis on such behaviors on the policy arena may lead to unpredictable shifts in scientists behaviors and possible undesirable behaviors.

The legal and institutional infrastructure to facilitate technology transfer from universities to industry is already in place. My results imply that any further efforts in this direction may be inefficient at best, and detrimental at the worst. Stories of commercial successes of university inventions abound, but their occurrence is too random and unpredictable to serve as a basis for national S&T policy. Instead, focusing on incentives to even better integrate the commercial utilization of what universities already do best and the most of, may be more sustainable and more appropriate in the future.

In addition to the mentioned legislation, there is also a broad spectrum of programs and tools attempting in their different ways to bring closer the academic research and industry. Some of these are federal or state initiatives implemented as part of the respective agencies' missions, and some of them are triggered or encouraged by the above legislation.

In the first category one could find a very diverse set of partnership programs (Coburn & Berglund, 1995). Some of the most notable ones include the NSF supported research centers, university based research parks, university based technology incubators, and different state level technology initiatives such as research parks, centers of excellence, extension programs etc. In the second category, one could observe the accelerated establishment of university technology transfer offices in the post Bayh-Dole era.

The various types of technology partnerships and boundary-spanning institutions attempt different strategies to establish closer links between universities and industry. More important in the current argument however is that none of them – with some important exceptions discussed below – has anything to do with students, with the training and education mission of universities. The priorities of these programs are heavily skewed towards technology development, technology financing, and industry problem solving while educational and training activities are far less, if at all emphasized (Coburn & Brown, 1997).Whether or not this should be the case of course depends on the particular goals and circumstances of such institutions. However, considering that universities are linked to most of these initiatives, and considering the results from this work, as well as indirect evidence from studies devoted specifically so such institutions, it may be prudent to consider mechanisms to involve educational and training components in such institutions. For example, even in the case of perhaps the least interactive (by design) institutions such as the technology incubators whose chief purpose is to provide basic business infrastructure for startups, one of the most important benefits reported by firms participating in university incubators is the access to university faculty and students (Lewis, 2001). Others have pointed out that research on technology incubation focuses exclusively on facilities, while neglecting the "true" needs of the clients of the incubator (Hackett & Dilts, 2004).

The results reported here that incorporating student-related components in such program may increase their attractiveness for industry and overall efficiency. If boundary-spanning programs and institutions are popular and grow in importance, and if there is direct and indirect evidence that firms are motivated by access to qualified human capital, then the training of next generation scholars in the university setting should perhaps incorporate exposure to industry-relevant research and to provide training in the norms and peculiarities of the technology transfer process. Since this study showed that interactions with industry are not the realm of marginalized scientists who could not otherwise “make it”, and since it demonstrated that an important component of these scientists’ ability to interact with the private sector, it then follows that it may be warranted to promote more intensive integration of student training with university relevant research, as a tool to promote such behaviors in future scientists. Once graduated, such students will be “less foreign” to an environment of intersection of academia and industry.

Implications for boundary spanning institutions that focus on education: NSF ERCs

NSF’s ERCs deserve particular attention in the discussion of the findings of this study. The reason is that before the inception of the ERC program in 1984, student education and training has not been typically addressed by the various centers programs. Important part of the mission of the ERCs is to “revolutionize engineering research and education by focusing more on interdisciplinary problems, building closer ties between industrial and academic research, and providing a different, more hands-on education for engineering undergraduate and graduate students” (Bozeman & Boardman, 2004). This explicit focus on education is one of the reasons why these institutions are indeed considered to be “revolutionary” (Bozeman & Boardman, 2004).

The results in this thesis provide evidence that such policy may be sensible and effective. The results presented here imply that the educational component of ERCs is not merely an add-on to the program goals (to perhaps bribe and put at ease university administrator and to more easily attract university scientists to affiliate with such centers), but an integral and important component of the institutional design to attract and retain industrial partners willing to invest in working relationship with university counterparts. The ERC program pays not only lip service to the need for sustaining and improving the relevance of the engineering education, but the goal of the ERCs is to provide continual interaction of academic researchers, students, and faculty with their industry peers. With this emphasis, it should come as no surprise that firms explicitly note that some of the chief benefits derived from interactions with ERCs is the access to qualified students (Feller, Ailes, & Roessner, 2002; Feller & Roessner, 1995).

Since the center affiliations reported in the survey encompass far more, and more diverse boundary-spanning institutions such as the ERCs, the results of this study - combined with the rationale of the ERC program – imply that increased emphasis on student involvement may be beneficial for other types of center programs as well. Since the positive relationship between student and industry involvement is registered while keeping affiliation with center constant, this implies first student involvement amplifies the already positive effect of center affiliation on interactions with industry. Further, this implies that center programs can take advantage of processes that occur “naturally” and channel such student interactions in ways best matching the center mission. Albeit research centers have slightly negative effects on teaching (Gaughan & Bozeman, 2005), they seem to have positive effects on graduate student grant support, which is one of the behaviors associated with increased industrial interactions as reported here. If so, then at least some of these centers seem to be successfully harnessing and amplifying these –

specific to graduate education – training and interaction functions towards accomplishment of their specific institutional goals.

Another important advantage of such institutional environments is that they provide conditions for scientists to pursue research goals and strategies such as interdisciplinary and more applied research, which are not always as easily pursued in the environment of the traditional academic departments. Among other things, this allows scientists in various positions to take advantage of resources and support system to allow them to compete and advance their careers in arenas not limited by the rigid status-based system of academic competition based exclusively on peer review. While this system has proven effective, it is also characterized with emphasis on rigid career paths and deliverables that may pose structural barriers for "non-traditional" scientists (for example – women and minorities) to succeed in academia. Centers may be one way to reduce or circumvent such structural limitations and to enhance the chances of relatively disadvantaged groups such as women: recent study has found a "gender equity" effect of centers that reduces the gender based research disadvantages (Corley & Gaughan, 2005). If such "equity effects" are a characteristic of such centers, then another possible implication of this study is that the relatively strong emphasis on student training may be a way to facilitate, support and sustain scientists' involvement with students (through the assistance of the center resources and infrastructure), by at (indirectly) relaxing the pressure to "publish at all costs", one unfortunate side effect of which in some cases may be the relative neglect of training and mentoring obligations.

If NSF wishes to increase the commercial orientation of its centers and their relevance to industry, the future actions of the centers and NSF should take into consideration the importance of the students as assets in these relationships. The current ERC evaluations include measures such as percent of industrial partners who have hired ERC student or graduate (Parker, 1997), however there is great variability in the proportion of partners reporting this outcome by center. Considering the consistently high rankings of the importance of students, and considering that more ERC partners report this outcome rather than outcomes such as improved products or processes, this is an area of ERCs operations that deserves sustained attention. From the student side of the equation, the most important benefit from working in ERCs for graduate students is the ability to work and establish contacts with industry (Parker, 1997).

One could question whether it is worth it to create specialized institutional forms that to some extent seem to replicate processes that occur naturally (e.g. the positive relationship between students and industry involvement holds regardless of center affiliation). The answer is affirmative, found both in the assumptions of the ERC program and one of its evaluations. One of the assumptions of the ERC program is that ERC activities of student build on and are complementary to the traditional graduate education. When asked to rank the relative importance of ERC and non-ERC activities on their careers, students who have graduated report positive effects of both, but in different aspects. The ERC activities positively impacted their careers in the program's intended ways by enhancing students; ability to work in interdisciplinary teams, to communicate ideas, and ability to solve problems under time and money constraints (Parker, 1997). Thus, while traditional graduate education positively impacts the industrial careers of students (as also implied by the results presented in this text), the research centers target and develop skill areas that are also important for industry but less emphasized in traditional graduate education. Centers do not come to replace the university education. They however provide some shortcuts for faster and more flexible response to particular needs originating in industry. Satisfying such needs however is not in conflict with, but complementary to standard education.

Another policy implication has to deal with the dominant mechanisms of grant funding and support of science. Upon the inception of the ERC and related center programs, the academic community voiced concerns that these new institutional forms will "take away" the funding previously given to individual researchers (Bozeman & Boardman, 2004). My results suggest that no attempts should be made to tilt the funding balance in favor of the center-based research. Such institutions should exist and be developed in conjunction, not instead of the PI-initiated, small science funding model. My models identified independent positive effect of government grants on interactions with industry. Further, I also identified that the majority of this impact is meditated by student involvement. This implies that government funding may have nearer term (albeit still indirect) effects on private sector innovation than merely the published knowledge resulting from such funding. That is, government funding, as implied from results reported here is certainly not merely a tool to satisfy researcher's intellectual curiosity, but it aids in the fulfillment of the training missions of universities and thus also aids interactions with the private sector.

Implications for the academic recruitment and retention

One concern sometimes voiced among higher education scholars is that the reward system of the traditional, department based academic science may discourage scientists, especially junior ones, from pursuing industrially relevant research (Geisler, 1989). Since the work of Blumenthal and colleagues (Blumenthal, Gluck, Louis, Stoto, & Wise, 1986), evidence has been mounting that industrial interactions are not the realm of marginalized scholars, but on the contrary – of ones who generally perform as scientists at least as well, if not better than colleagues who are not industrially involved. Considering the positive association between industry interactions and productivity, collaboration, grants – and now with this study – student involvement, it seems that reasons to consider possible adjustments of the academic rewards system, and particularly the criteria used in tenure and promotion decisions, are increasing. Such possible adjustments certainly do not imply a departure from the basic criteria for evaluating scientific merit – the amount and the quality of scholarly contributions published in peer-reviewed outlets whish is and should remain the major measure of scientific contributions. However, other important roles and missions that scientists must fulfill such as training, and increasingly more so – public service and evidence of meaningful impacts of scholarly work, should not suffer from being perceived as distraction from “what really matters”. The mounting evidence regarding the complementarity between traditional and the more diverse contemporary perceptions of what science and scientists “should do”, implies that more well rounded evaluations, taking into consideration broader range of impacts and contributions of scientists would be appropriate.

Such changes are only partially a matter of policy, as they have to do with deeply embedded norms of the academic community. Nevertheless, norms and communities respond to incentives. Certain incentives and institutional emphases could indirectly influence these evaluation processes, without the risk of causing major and unpredictable changes. For example, albeit the number of students graduated, mentored and collaborated with is considered a part of almost all faculty evaluations, the relative emphasis on this dimension varies tremendously across departments in the research extensive universities. Some schools place greater emphasis on mentoring and training activities (sometimes such emphasis is so prominent, that scientists feel compelled to list this type of contributions in the front of their CV, even before their publication and scholarly record). In other institutions, the consideration of training and mentoring activities is less important. More research is needed on the particular determinants of the variances in emphasis on training and student-related activities, but it is a justified policy concern to attempt measures to ensure sustained commitment of faculty to student development.

Most importantly from policy point of view is that changes as the ones suggested above will not necessarily go against the traditional beliefs shared by the academic community. The finding that not only interactions with industry are not achieved at the expense of core missions, but strengthened by them allows shifting evaluation emphasis towards more traditional university roles without ignoring the desired closer integration with industry.

The use of these findings can be difficult to promote “across the board” in tenure and promotion decisions because of the above mentioned important role of the norms and standards of the academic community, many of them not sanctioned institutionally. However, even such norms changes given the proper policy incentives. Given that the emphasis of policy makers and university administrators place on fostering linkages with industry is unlikely to diminish in the foreseeable future, one indirect way for universities and departments to position themselves better for such interactions could be more explicit consideration given to the record of student involvement of new job candidates. While involvement with students does not “guarantee” involvement with industry, departments contemplating ways to increase their connections with the private sector, but wary of dramatic changes, may wish to consider in their hiring decisions the student involvement of job candidates as indirect ways to possibly enhance their industrial connections without having to “bend over” in order to accommodate more drastic arrangements.

So what's the optimal role for students in the process of university industry collaboration? How best do you balance education with collaborative research without sacrificing the integrity of either? It seems best to err on the side of caution, to prevent capture that some assert is happening. In the context of the present findings, above all, this means not to overstate them. The major policy implication of this work is that universities do contribute to private sector innovation chiefly indirectly, through doing what they do best: academic research and instruction. My results reaffirm that these activities spill over onto private sector firms through numerous mechanisms., and some of the important inputs into private sector innovation may be immediate and direct and to occur in the context of individual scientists’ interactions with private companies.

Another implication of this work is that too aggressive an attempt to increase the commercial relevance of academia by mandating or selectively encouraging more applied work or deliverables “for industry” would be ill-advised. Ironically, with few exceptions this has been the case in the US science policy in the recent years. If for no other reason, such policies are questionable since they devote resources to promoting marginal outputs of universities that represent miniscule part of their core missions while not considering how similar or better results could be achieved by careful emphasis on what universities do best, and the most of – research and training.

APPENDIX

Table 1. Summary statistics of the sample by gender, tenure status, career age and post-doc experience

Variable	Obs	Mean	Std. Dev.	Min	Max
Male	1643	.49	.5	0	1
Has held post-doctoral position	1610	.5	.5	0	1
Tenured	1643	.73	.5	0	1
Years since completing the PhD	1603	16.92	11.1	0	52

Table 2. Descriptive statistics - student related behaviors

Variable	Obs	Mean	Std. Dev.	Min	Max
Number of masters students supported currently by grants	1643	0.88	1.50	0	20
Number of doctoral students supported currently by grants	1643	2.02	2.55	0	25
Number of graduate students collaborated with on research during the past 12 months	1646	4.53	7.96	0	220
Agrees that Interest in helping graduate students is important in my decisions to collaborate	1615	3.18	0.82	1	4
Average hours per week devoted to teaching undergraduate students (including preparation time and meeting outside class)	1642	9.67	8.35	0	50
Average hours per week devoted to teaching graduate students (including preparation time and meeting outside class)"	1641	6.37	6.31	0	84
Average hours per week devoted to advising graduate and undergraduate students on curriculum and job placement	1641	2.47	3.02	0	30
Average hours per week devoted to teaching (including preparation time and meeting outside class)	1641	16.12	10.29	0	96
Number of graduate students (masters or doctoral) supported currently by grants	1646	2.9	3.15	0	40

Table 3. Descriptive statistics - industry related behaviors

Variable	Obs	Mean	Std. Dev.	Min	Max
Any kind of interaction with industry	1616	0.52	0.50	0	1
Was contacted by industrial company about his or her research and has provided it	1643	0.37	0.48	0	1
Contacted industrial company about their research or research interests	1643	0.19	0.39	0	1
Served as a formal paid consultant to an industrial firm	1643	0.18	0.39	0	1
Helped place graduate students or post-docs in industry jobs	1643	0.25	0.43	0	1
Worked in industrial company as a partner, owner or employee	1643	0.04	0.18	0	1
Worked directly with industry personnel in work that resulted in a patent or copyright	1643	0.06	0.23	0	1
Worked directly industry personnel on an effort to commercialize technology or applied research	1643	0.16	0.37	0	1
Co-authored a paper with industry personnel that has been published in a journal or refereed proceedings	1643	0.15	0.36	0	1
Industrial involvement scale	1643	1.08	1.44	0	6.62

Table 4. Mean comparisons of student related behaviors between scientists who interact with industry and the ones who do not (t-tests, 2-tailed)

T-test of mean differences	Does not interact with industry	Interacted with industry	Mean difference	Sig. (2-tailed)
Number of masters students supported currently by grants	0.51	1.23	0.72	***
Number of doctoral students supported currently by grants	1.48	2.55	1.06	***
Number of graduate students collaborated with on research during the past 12 months	3.37	5.67	2.30	***
Agrees that Interest in helping graduate students is important in my decisions to collaborate	3.06	3.29	0.24	***
Average hours per week devoted to teaching undergraduate students (including preparation time and meeting outside class)	10.32	9.09	-1.23	***
Average hours per week devoted to teaching graduate students (including preparation time and meeting outside class)"	6.42	6.34	-0.08	NS
Average hours per week devoted to teaching (including preparation time and meeting outside class)	16.75	15.44	-1.31	***
Average hours per week devoted to advising graduate and undergraduate students on curriculum and job placement	2.40	2.56	0.16	NS
Number of graduate students (masters or doctoral) supported currently by grants	1.99	3.78	1.78	***

* significant at 10%; ** significant at 5%; *** significant at 1%, NS not statistically significant

Table 5. Means of student-related behaviors by discipline

	grantma	grantphd	gradcol	gradment	teachugr	teachgrad	advise	totteach	grantgrad
BIOL	0.25	1.49	2.80	2.89	10.45	5.61	2.13	16.06	1.74
CS	0.96	2.11	5.49	3.10	8.69	7.92	2.93	16.62	3.07
MATH	0.13	0.85	1.30	2.77	11.19	7.21	1.85	18.40	0.98
PHYS	0.21	1.78	5.23	3.18	10.13	5.11	2.13	15.24	1.99
EAS	0.79	1.21	4.23	3.30	9.34	7.73	2.77	17.07	2.00
CHEM	0.27	2.98	4.22	3.12	10.06	6.09	2.03	16.15	3.24
AGRI	0.84	0.86	3.13	3.22	7.10	4.54	2.83	11.64	1.70
CHE	0.97	3.33	4.96	3.36	11.55	5.46	2.19	17.00	4.29
CE	1.80	1.97	5.65	3.30	8.92	7.32	2.67	16.25	3.76
EE	1.43	3.02	6.44	3.37	9.43	6.50	2.68	15.92	4.45
ME	1.45	1.78	4.93	3.14	10.65	6.53	2.81	17.18	3.24
MTE	1.17	3.44	5.37	3.29	9.09	5.80	2.38	14.89	4.62

Table 6. Means of industry-related behaviors by discipline

	indscinf	scindinf	consult	studplace	workind	patented	techtrsf	coauthor
BIOL	0.13	0.07	0.09	0.04	0.02	0.02	0.04	0.03
CS	0.39	0.22	0.17	0.30	0.03	0.05	0.20	0.18
MATH	0.03	0.01	0.07	0.04	0.00	0.00	0.01	0.03
PHYS	0.13	0.05	0.02	0.05	0.01	0.02	0.05	0.07
EAS	0.21	0.07	0.11	0.11	0.01	0.01	0.04	0.07
CHEM	0.27	0.09	0.15	0.21	0.01	0.02	0.14	0.08
AGRI	0.54	0.26	0.23	0.29	0.03	0.07	0.35	0.18
CHE	0.55	0.32	0.26	0.35	0.05	0.11	0.30	0.23
CE	0.55	0.23	0.32	0.46	0.07	0.05	0.14	0.21
EE	0.42	0.33	0.22	0.33	0.09	0.06	0.23	0.23
ME	0.64	0.32	0.23	0.39	0.04	0.12	0.22	0.23
MTE	0.61	0.35	0.33	0.44	0.08	0.15	0.28	0.29

Table 7. Means comparisons of student related behaviors by tenure status (t-tests, 2-tailed)

T-test of mean differences	Not tenured	Tenured	Mean difference	Sig. (2-tailed)
Number of masters students supported currently by grants	0.74	0.93	0.19	**
Number of doctoral students supported currently by grants	1.50	2.22	0.72	***
Number of graduate students collaborated with on research during the past 12 months	3.75	4.84	1.09	**
Agrees that Interest in helping graduate students is important in my decisions to collaborate	3.02	3.24	0.22	***
Average hours per week devoted to teaching undergraduate students (including preparation time and meeting outside class)	10.00	9.58	-0.42	NS
Average hours per week devoted to teaching graduate students (including preparation time and meeting outside class)"	6.75	6.25	-0.50	NS
Average hours per week devoted to teaching (including preparation time and meeting outside class)	16.75	15.83	-0.92	*
Average hours per week devoted to advising graduate and undergraduate students on curriculum and job placement	2.22	2.58	0.35	**
Number of graduate students (masters or doctoral) supported currently by grants	2.24	3.15	0.90	***

* significant at 10%; ** significant at 5%; *** significant at 1%, NS not statistically significant

Table 8. Means comparisons of industry related behaviors by tenure status (t-tests, 2-tailed)

T-test of mean differences	Not tenured	Tenured	Mean difference	Sig. (2-tailed)
Any kind of interaction with industry	0.45	0.53	0.08	***
Was contacted by industrial company about his or her research and has provided it	0.31	0.40	0.09	***
Contacted industrial company about their research or research interests	0.18	0.19	0.01	NS
Served as a formal paid consultant to an industrial firm	0.11	0.21	0.10	***
Helped place graduate students or post-docs in industry jobs	0.16	0.29	0.13	***
Worked in industrial company as a partner, owner or employee	0.02	0.04	0.02	**
Worked directly with industry personnel in work that resulted in a patent or copyright	0.04	0.06	0.02	NS
Worked directly industry personnel on an effort to commercialize technology or applied research	0.11	0.18	0.07	**
Co-authored a paper with industry personnel that has been published in a journal or refereed proceedings	0.12	0.16	0.05	**
Industrial involvement scale	0.80	1.18	0.38	***

* significant at 10%; ** significant at 5%; *** significant at 1%, NS not statistically significant

Table 9. Determinants of collaboration and productivity OLS regression results (non-standardized coefficients)

	(1)	(2)	(3)
	Total number of research collaborators (not including graduate students)	Total number of peer-reviewed journal articles (imputed)	Total number of peer-reviewed journal articles
Biology	-0.173	4.869	8.959
	(4.892)	(4.678)	(7.898)
Mathematics	-0.616	-4.421	-2.200
	(5.053)	(4.628)	(8.150)
Physics	10.822**	24.545***	24.529***
	(4.673)	(4.473)	(7.324)
Earth and Atmospheric Sciences	9.863**	13.192***	12.072*
	(4.538)	(4.171)	(6.708)
Chemistry	-0.124	25.560***	23.951***
	(4.785)	(4.529)	(7.600)
Agriculture	1.532	6.695	6.361
	(4.813)	(4.374)	(7.119)
Chemical Engineering	-1.342	18.040***	20.397***
	(4.918)	(4.437)	(7.387)
Civil Engineering	-0.080	5.066	7.204
	(4.529)	(4.080)	(6.518)
Electrical Engineering	-0.353	4.263	4.652
	(4.880)	(4.386)	(7.368)
Mechanical Engineering	-1.584	3.127	5.198
	(4.685)	(4.247)	(6.854)
Materials Engineering	-0.592	47.952***	39.887***
	(5.250)	(4.775)	(7.910)
Tenured	4.842*	12.956***	9.507*
	(2.742)	(2.962)	(4.980)
Male	3.158	8.875***	8.162***
	(2.080)	(1.874)	(3.158)
Number of years since completing the PhD degree	-0.252**	-0.217	0.602
	(0.116)	(0.375)	(0.646)
Affiliated with university research center	4.533**	1.958	-1.742
	(2.133)	(1.930)	(3.159)
Years since completing the PhD degree squared		0.050***	0.033**
		(0.008)	(0.014)

Table 9 (continued)

Had post-doctoral appointment		10.916***	10.907***
		(2.029)	(3.317)
Total number of research collaborators (not including graduate students)		0.375***	1.006***
		(0.080)	(0.220)
Has had industrial experience		-0.130	-0.209
		(1.857)	(3.302)
Squared number of collaborators		-0.000***	-0.001***
		(0.000)	(0.000)
Constant	4.350	-9.052**	-17.095**
	(3.802)	(3.952)	(6.742)
Observations	1599	1591	807
R-squared	0.02	0.45	0.33

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 10. Determinants of grants by source - summary OLS regressions, non-standardized coefficients

	(1)	(2)	(3)
	Total number of active grants	Number of active industry grants	Number of active government grants
Male	-0.024	0.012	-0.036
	(0.052)	(0.023)	(0.047)
Biology	-0.335***	-0.214***	-0.121
	(0.129)	(0.058)	(0.115)
Mathematics	-0.734***	-0.223***	-0.511***
	(0.129)	(0.058)	(0.115)
Physics	-0.359***	-0.207***	-0.152
	(0.124)	(0.055)	(0.110)
Earth and Atmospheric Sciences	-0.237**	-0.203***	-0.035
	(0.116)	(0.052)	(0.104)
Chemistry	-0.224*	-0.158***	-0.067
	(0.126)	(0.057)	(0.113)
Agriculture	-0.477***	-0.073	-0.404***
	(0.120)	(0.054)	(0.107)
Chemical Engineering	0.173	0.077	0.096
	(0.123)	(0.055)	(0.110)
Civil Engineering	-0.232**	-0.145***	-0.087
	(0.113)	(0.051)	(0.101)
Electrical Engineering	0.138	-0.021	0.159
	(0.121)	(0.054)	(0.108)
Mechanical Engineering	0.181	0.059	0.122
	(0.117)	(0.052)	(0.104)
Materials Engineering	0.249*	-0.075	0.323***
	(0.135)	(0.061)	(0.121)
Tenured	0.453***	0.071**	0.382***
	(0.069)	(0.031)	(0.061)
Number of years since completing the PhD degree	-0.028***	-0.003**	-0.025***
	(0.003)	(0.001)	(0.003)
Affiliated with university research center	0.440***	0.082***	0.358***
	(0.053)	(0.024)	(0.048)
Had post-doctoral appointment	0.010	-0.058**	0.068
	(0.057)	(0.025)	(0.051)
Total number of research collaborators (not including graduate students)	0.001**	-0.000	0.001**
	(0.001)	(0.000)	(0.001)

Table 10 (continued)

Total number of peer-reviewed journal articles (imputed)	0.006***	0.000	0.005***
	(0.001)	(0.000)	(0.001)
Agrees that worrying about possible commercial applications distracts one from doing good research	-0.051*	-0.012	-0.039
	(0.027)	(0.012)	(0.024)
Has had industrial experience	0.015	-0.014	0.029
	(0.051)	(0.023)	(0.046)
Constant	1.327***	0.255***	1.072***
	(0.116)	(0.052)	(0.103)
Observations	1548	1548	1548
R-squared	0.21	0.08	0.19

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 11. Determinants of student-related behaviors - summary OLS regression results, non-standardized coefficients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Average hours per week devoted to teaching graduate students (including preparation time and meetings outside class)	Average hours per week devoted to advising graduate and undergraduate students on curriculum and job placement	Average hours per week devoted to teaching undergraduate students (including preparation time and meetings outside class)	Average hours per week devoted to teaching(including preparation time and meetings outside class)	Agrees that interest in helping graduate students is important in my decisions to collaborate	Number of masters students supported currently by grants	Number of doctoral students supported currently by grants	Number of graduate students (masters or doctoral) supported currently by grants	Number of graduate students collaborated with on research during the past 12 months
Male	-0.049	-0.254	-0.643	-0.690	-0.119***	0.044	-0.222**	-0.179	0.385
	(0.338)	(0.163)	(0.438)	(0.509)	(0.044)	(0.074)	(0.109)	(0.131)	(0.324)
Biology	-2.947***	-0.799**	1.980*	-0.978	-0.195*	-0.466**	-0.428	-0.894***	-2.032**
	(0.837)	(0.404)	(1.084)	(1.261)	(0.109)	(0.183)	(0.270)	(0.324)	(0.804)
Mathematics	-0.908	-1.127***	1.829*	0.908	-0.218**	-0.468**	-0.399	-0.867***	-2.756***
	(0.840)	(0.405)	(1.088)	(1.266)	(0.109)	(0.184)	(0.271)	(0.325)	(0.807)
Physics	-3.226***	-0.737*	2.473**	-0.765	0.118	-0.579***	-0.633**	-1.212***	-1.369*
	(0.802)	(0.387)	(1.039)	(1.209)	(0.105)	(0.175)	(0.258)	(0.310)	(0.770)
Earth and Atmospheric Sciences	-0.404	-0.066	1.480	1.063	0.183*	-0.064	-1.135***	-1.199***	-2.534***
	(0.753)	(0.363)	(0.975)	(1.134)	(0.098)	(0.164)	(0.242)	(0.291)	(0.722)
Chemistry	-2.184***	-0.855**	2.690**	0.495	0.040	-0.570***	0.281	-0.289	-1.361*
	(0.818)	(0.395)	(1.060)	(1.233)	(0.107)	(0.179)	(0.263)	(0.316)	(0.785)

Table 11 (continued)

Agriculture	-3.332***	-0.126	-2.468**	-5.815***	0.138	0.071	-0.933***	-0.862***	-2.162***
	(0.777)	(0.375)	(1.007)	(1.171)	(0.101)	(0.170)	(0.250)	(0.301)	(0.746)
Chemical Engineering	-2.756***	-0.761**	4.252***	1.482	0.250**	-0.099	0.392	0.293	-1.347*
	(0.794)	(0.383)	(1.029)	(1.196)	(0.103)	(0.173)	(0.255)	(0.306)	(0.760)
Civil Engineering	-0.376	-0.083	0.358	-0.033	0.227**	0.892***	-0.276	0.615**	0.056
	(0.729)	(0.353)	(0.945)	(1.099)	(0.095)	(0.159)	(0.235)	(0.282)	(0.700)
Electrical Engineering	-1.486*	-0.470	1.615	0.124	0.283***	0.389**	0.370	0.758**	0.351
	(0.783)	(0.377)	(1.012)	(1.180)	(0.102)	(0.171)	(0.251)	(0.302)	(0.750)
Mechanical Engineering	-1.469*	-0.229	2.521**	1.037	0.049	0.502***	-0.689***	-0.187	-0.742
	(0.754)	(0.364)	(0.978)	(1.137)	(0.099)	(0.165)	(0.243)	(0.292)	(0.724)
Materials Engineering	-2.243**	-0.434	3.221***	0.966	0.152	0.021	-0.080	-0.059	-1.740**
	(0.876)	(0.423)	(1.136)	(1.321)	(0.114)	(0.192)	(0.282)	(0.339)	(0.841)
Tenured	-0.338	0.320	-0.074	-0.405	0.178***	0.309***	0.788***	1.097***	1.297***
	(0.449)	(0.217)	(0.582)	(0.677)	(0.059)	(0.098)	(0.144)	(0.174)	(0.431)
Number of years since completing the PhD degree	-0.038*	0.005	0.028	-0.011	0.002	-0.016***	-0.056***	-0.072***	-0.090***
	(0.022)	(0.010)	(0.028)	(0.033)	(0.003)	(0.005)	(0.007)	(0.008)	(0.021)
Had post-doctoral appointment	0.724**	0.031	0.117	0.839	-0.017	-0.221***	-0.082	-0.303**	-0.197
	(0.366)	(0.177)	(0.474)	(0.552)	(0.048)	(0.080)	(0.118)	(0.142)	(0.352)

Table 11 (continued)

Affiliated with university research center	0.022	0.002	-1.626***	-1.608***	0.031	0.042	0.706***	0.748***	0.774**
	(0.351)	(0.169)	(0.455)	(0.529)	(0.046)	(0.077)	(0.113)	(0.136)	(0.337)
Total number of research collaborators (not including graduate students)	0.000	-0.001	-0.004	-0.004	0.000	0.003***	-0.001	0.002	0.128***
	(0.004)	(0.002)	(0.005)	(0.006)	(0.001)	(0.001)	(0.001)	(0.002)	(0.004)
Total number of peer-reviewed journal articles (imputed)	0.007	-0.000	-0.026***	-0.019***	0.000	0.002	0.017***	0.019***	0.017***
	(0.005)	(0.002)	(0.006)	(0.007)	(0.001)	(0.001)	(0.002)	(0.002)	(0.005)
Number of active government grants	-0.181	-0.128	-1.025***	-1.206***	0.014	0.310***	0.875***	1.185***	0.951***
	(0.185)	(0.089)	(0.240)	(0.279)	(0.024)	(0.040)	(0.060)	(0.072)	(0.178)

Table 11 (continued)

Number of active industry grants	0.277	0.197	-0.389	-0.105	0.086*	0.275***	0.710***	0.985***	0.695**
	(0.368)	(0.178)	(0.477)	(0.555)	(0.048)	(0.081)	(0.119)	(0.143)	(0.354)
Agrees that worrying about possible commercial applications distracts one from doing good research	0.019	0.063	0.112	0.129	-0.002	0.038	-0.054	-0.016	-0.200
	(0.176)	(0.085)	(0.228)	(0.265)	(0.023)	(0.039)	(0.057)	(0.068)	(0.169)
Has had industrial experience	-0.228	0.189	-0.037	-0.269	0.024	-0.036	-0.048	-0.084	0.837***
	(0.331)	(0.160)	(0.429)	(0.499)	(0.043)	(0.072)	(0.107)	(0.128)	(0.318)
Constant	8.590***	2.678***	10.760***	19.372***	2.915***	0.443***	0.930***	1.374***	3.132***
	(0.778)	(0.376)	(1.008)	(1.172)	(0.102)	(0.170)	(0.251)	(0.301)	(0.747)
Observations	1543	1543	1544	1543	1531	1548	1548	1548	1548
R-squared	0.04	0.02	0.07	0.07	0.06	0.21	0.38	0.42	0.48

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 12. Determinants of industrial involvement scale (nonstandardized coefficients)

	(1)	(2)	(3)	(4)
	Industrial Involvement Scale	Industrial Involvement Scale	Industrial Involvement Scale	Industrial Involvement Scale
Male	0.197***	0.207***	0.193**	0.203***
	(0.064)	(0.064)	(0.089)	(0.064)
Tenured	0.130	0.143*	0.127	0.125
	(0.087)	(0.087)	(0.118)	(0.087)
Biology	-0.373**	-0.361**	-0.427*	-0.377**
	(0.160)	(0.160)	(0.225)	(0.159)
Mathematics	-0.507***	-0.487***	-0.447*	-0.517***
	(0.160)	(0.160)	(0.231)	(0.160)
Physics	-0.554***	-0.537***	-0.516**	-0.540***
	(0.154)	(0.154)	(0.210)	(0.151)
Earth and Atmospheric Sciences	-0.512***	-0.537***	-0.418**	-0.504***
	(0.144)	(0.144)	(0.192)	(0.143)
Chemistry	-0.257	-0.217	-0.232	-0.249
	(0.157)	(0.157)	(0.213)	(0.154)
Agriculture	0.522***	0.502***	0.558***	0.524***
	(0.149)	(0.149)	(0.198)	(0.148)
Chemical Engineering	0.224	0.234	0.384*	0.241
	(0.151)	(0.153)	(0.207)	(0.150)
Civil Engineering	0.306**	0.320**	0.298	0.312**
	(0.140)	(0.140)	(0.183)	(0.140)
Electrical Engineering	0.060	0.069	0.284	0.063
	(0.149)	(0.150)	(0.206)	(0.149)
Mechanical Engineering	0.427***	0.439***	0.348*	0.431***
	(0.144)	(0.144)	(0.192)	(0.144)
Materials Engineering	0.355**	0.380**	0.275	0.384**
	(0.166)	(0.167)	(0.224)	(0.163)

Table 12 (continued)

Number of years since completing the PhD degree	0.004	0.003	-0.003	0.006
	(0.004)	(0.004)	(0.006)	(0.004)
Total number of research collaborators (not including graduate students)	-0.000	-0.000	-0.002	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Agrees that worrying about possible commercial applications distracts one from doing good research	-0.130***	-0.131***	-0.065	-0.129***
	(0.034)	(0.033)	(0.046)	(0.034)
Had post-doctoral appointment	-0.259***	-0.260***	-0.224**	-0.257***
	(0.070)	(0.070)	(0.094)	(0.069)
Affiliated with university research center	0.219***	0.234***	0.197**	0.213***
	(0.068)	(0.068)	(0.090)	(0.068)
Has had industrial experience	0.065	0.058	0.050	
	(0.063)	(0.063)	(0.092)	
Number of active government grants	0.091**	0.099***	0.054	0.094**
	(0.038)	(0.038)	(0.053)	(0.038)
Number of active industry grants	0.713***	0.706***	0.870***	0.711***
	(0.071)	(0.071)	(0.098)	(0.071)
Total number of peer-reviewed journal articles (imputed)	0.001	0.001		
	(0.001)	(0.001)		
Number of masters students supported currently by grants	0.100***	0.095***	0.071**	0.100***
	(0.022)	(0.023)	(0.034)	(0.022)
Number of doctoral students supported currently by grants	0.087***	0.076***	0.048**	0.089***
	(0.015)	(0.016)	(0.022)	(0.015)
Number of graduate students collaborated with on research during the past 12 months	0.009*	0.008	0.027**	0.010*
	(0.005)	(0.005)	(0.012)	(0.005)

Table 12 (continued)

Agrees that Interest in helping graduate students is important in my decisions t	0.103***	0.103***	0.087*	0.104***
	(0.038)	(0.038)	(0.052)	(0.038)
Average hours per week devoted to teaching graduate students (including preparation time and meetings outside class)		-0.002		
		(0.005)		
Average hours per week devoted to teaching undergraduate students (including preparation time and meetings outside class)		-0.005		
		(0.004)		
Average hours per week devoted to advising graduate and undergraduate students on curriculum and job placement		0.014		
		(0.010)		
Total number of peer-reviewed journal articles			0.002	
			(0.001)	
Constant	0.298	0.334*	0.266	0.308*
	(0.184)	(0.193)	(0.253)	(0.180)
Observations	1531	1525	776	1531
R-squared	0.35	0.35	0.36	0.35

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 13. Linear probability models for the different types of industrial interactions (non-standardized OLS coefficients)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Was contacted by industrial company about his or her research and has provided i	Contacted industrial company about their research or research interests	Served as a formal paid consultant to an industrial firm	Helped place graduate students or post-docs in industry jobs	Worked in industrial company as a partner, owner or employee	Worked directly with industry personnel in work that resulted in a patent or copyright	Worked directly industry personnel on an effort to commercialize technology or a	Co-authored a paper with industry personnel that has been published in a journal
Male	0.017	0.015	0.079***	0.032	0.032***	0.006	0.043**	0.016
	(0.023)	(0.020)	(0.020)	(0.021)	(0.010)	(0.012)	(0.019)	(0.018)
Tenured	0.095***	-0.024	0.043	0.079***	0.000	-0.005	0.016	-0.015
	(0.031)	(0.027)	(0.027)	(0.028)	(0.013)	(0.016)	(0.025)	(0.025)
Biology	-0.129**	-0.064	0.005	-0.144***	-0.014	0.004	-0.070	-0.081*
	(0.057)	(0.050)	(0.050)	(0.052)	(0.024)	(0.030)	(0.046)	(0.046)
Mathematics	-0.223***	-0.115**	-0.036	-0.112**	-0.019	-0.010	-0.090*	-0.067
	(0.057)	(0.050)	(0.050)	(0.052)	(0.024)	(0.030)	(0.046)	(0.046)
Physics	-0.185***	-0.104**	-0.108**	-0.166***	-0.021	0.005	-0.076*	-0.074*
	(0.055)	(0.048)	(0.048)	(0.050)	(0.023)	(0.028)	(0.044)	(0.044)
Earth and Atmospheric Sciences	-0.152***	-0.109**	-0.040	-0.141***	-0.026	-0.017	-0.095**	-0.083**
	(0.052)	(0.045)	(0.045)	(0.047)	(0.022)	(0.027)	(0.041)	(0.041)
Chemistry	-0.069	-0.077	0.014	-0.041	-0.022	-0.001	-0.046	-0.084*
	(0.056)	(0.049)	(0.049)	(0.051)	(0.024)	(0.029)	(0.045)	(0.045)
Agriculture	0.205***	0.083*	0.071	0.041	0.004	0.034	0.210***	0.029
	(0.053)	(0.047)	(0.046)	(0.048)	(0.023)	(0.027)	(0.043)	(0.042)
Chemical Engineering	0.101*	0.061	0.052	-0.028	0.002	0.044	0.077*	-0.021
	(0.054)	(0.047)	(0.047)	(0.049)	(0.023)	(0.028)	(0.043)	(0.043)

Table 13 (continued)

Civil Engineering	0.139***	0.009	0.154***	0.128***	0.024	-0.015	-0.055	0.032
	(0.050)	(0.044)	(0.044)	(0.045)	(0.021)	(0.026)	(0.040)	(0.040)
Electrical Engineering	-0.047	0.080*	0.019	-0.040	0.053**	-0.007	-0.007	0.000
	(0.054)	(0.047)	(0.047)	(0.048)	(0.023)	(0.028)	(0.043)	(0.043)
Mechanical Engineering	0.224***	0.083*	0.075*	0.061	0.003	0.064**	0.026	0.031
	(0.052)	(0.045)	(0.045)	(0.047)	(0.022)	(0.027)	(0.041)	(0.041)
Materials Engineering	0.130**	0.114**	0.092*	0.045	-0.005	0.049	0.000	0.036
	(0.060)	(0.052)	(0.052)	(0.054)	(0.025)	(0.031)	(0.048)	(0.048)
Number of years since completing the PhD degree	-0.002	0.000	0.001	-0.000	0.001	0.001*	0.001	0.002
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Total number of research collaborators (not including graduate students)	0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 13 (continued)

Agrees that worrying about possible commercial applications distracts one from doing good research	-0.019	-0.016	-0.020*	-0.021*	-0.026***	-0.016***	-0.024**	-0.015
	(0.012)	(0.011)	(0.011)	(0.011)	(0.005)	(0.006)	(0.010)	(0.010)
Had post-doctoral appointment	-0.064**	-0.021	-0.090***	-0.045**	0.003	-0.015	-0.059***	-0.042**
	(0.025)	(0.022)	(0.022)	(0.023)	(0.011)	(0.013)	(0.020)	(0.020)
Affiliated with university research center	0.087***	0.048**	0.012	0.063***	0.002	0.004	0.019	0.056***
	(0.024)	(0.021)	(0.021)	(0.022)	(0.010)	(0.013)	(0.019)	(0.019)
Has had industrial experience	0.036	0.030	0.000	0.040*	0.014	-0.006	-0.023	-0.000
	(0.023)	(0.020)	(0.020)	(0.020)	(0.010)	(0.012)	(0.018)	(0.018)
Number of active government grants	0.037***	-0.002	0.024**	0.023*	0.001	0.004	0.022**	0.009

Table 13 (continued)

	(0.014)	(0.012)	(0.012)	(0.012)	(0.006)	(0.007)	(0.011)	(0.011)
Number of active industry grants	0.144***	0.156***	0.068***	0.149***	0.012	0.076***	0.119***	0.172***
	(0.025)	(0.022)	(0.022)	(0.023)	(0.011)	(0.013)	(0.020)	(0.020)
Total number of peer-reviewed journal articles (imputed)	0.000	-0.000	0.000	0.000	0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of masters students supported currently by grants	0.015*	0.022***	0.004	0.033***	0.003	0.014***	0.018***	0.015**
	(0.008)	(0.007)	(0.007)	(0.007)	(0.003)	(0.004)	(0.006)	(0.006)
Number of doctoral students supported currently by grants	0.018***	0.013**	0.008*	0.020***	0.007***	0.007**	0.024***	0.012***
	(0.006)	(0.005)	(0.005)	(0.005)	(0.002)	(0.003)	(0.004)	(0.004)

Table 13 (continued)

Number of graduate students collaborated with on research during the past 12 mon	0.002	0.001	0.001	0.005***	0.001	0.000	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Agrees that Interest in helping graduate students is important in my decisions t	0.037***	0.009	0.024**	0.049***	-0.000	0.005	-0.008	0.022**
	(0.014)	(0.012)	(0.012)	(0.012)	(0.006)	(0.007)	(0.011)	(0.011)
Constant	0.123*	0.119**	0.009	-0.053	0.030	0.010	0.117**	0.023
	(0.066)	(0.058)	(0.058)	(0.060)	(0.028)	(0.034)	(0.053)	(0.053)
Observations	1531	1531	1531	1531	1531	1531	1531	1531
R-squared	0.27	0.16	0.12	0.26	0.07	0.09	0.19	0.15

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 14. Tobit estimates and marginal effects for the industrial involvement scale

	(1)	(2)	(3)
	Latent variable	Conditional on being uncensored	Probability uncensored
Male	0.327***	0.122***	0.067***
	(0.124)	(0.046)	(0.025)
Tenured	0.261	0.095	0.054
	(0.167)	(0.062)	(0.034)
Biology	-1.144***	-0.368***	-0.227***
	(0.329)	(0.122)	(0.068)
Mathematics	-1.873***	-0.548***	-0.347***
	(0.372)	(0.138)	(0.076)
Physics	-1.644***	-0.501***	-0.314***
	(0.323)	(0.120)	(0.066)
Earth and Atmospheric Sciences	-1.193***	-0.385***	-0.237***
	(0.285)	(0.106)	(0.059)
Chemistry	-0.516*	-0.180	-0.106*
	(0.300)	(0.112)	(0.062)
Agriculture	1.005***	0.426***	0.198***
	(0.269)	(0.100)	(0.055)
Chemical Engineering	0.520*	0.207**	0.105*
	(0.270)	(0.100)	(0.055)
Civil Engineering	0.705***	0.286***	0.142***
	(0.252)	(0.094)	(0.052)
Electrical Engineering	0.235	0.090	0.048
	(0.270)	(0.100)	(0.055)
Mechanical Engineering	0.925***	0.387***	0.183***
	(0.258)	(0.096)	(0.053)
Materials Engineering	0.641**	0.260**	0.129**
	(0.297)	(0.110)	(0.061)
Number of years since completing the PhD degree	0.004	0.002	0.001
	(0.008)	(0.003)	(0.002)
Total number of research collaborators (not including graduate students)	0.000	0.000	0.000
	(0.002)	(0.001)	(0.000)
Agrees that worrying about possible commercial applications distracts one from doing good research	-0.239***	-0.089***	-0.049***
	(0.065)	(0.024)	(0.013)
Had post-doctoral appointment	-0.479***	-0.178***	-0.098***
	(0.132)	(0.049)	(0.027)

Table 14 (continued)

Affiliated with university research center	0.437***	0.166***	0.089***
	(0.126)	(0.047)	(0.026)
Has had industrial experience	0.146	0.055	0.030
	(0.119)	(0.044)	(0.024)
Number of active government grants	0.186***	0.069***	0.038***
	(0.071)	(0.026)	(0.015)
Number of active industry grants	0.912***	0.339***	0.187***
	(0.121)	(0.045)	(0.025)
Total number of peer-reviewed journal articles (imputed)	0.001	0.000	0.000
	(0.002)	(0.001)	(0.000)
Number of masters students supported currently by grants	0.101**	0.038**	0.021**
	(0.039)	(0.015)	(0.008)
Number of doctoral students supported currently by grants	0.117***	0.043***	0.024***
	(0.028)	(0.010)	(0.006)
Number of graduate students collaborated with on research during the past 12 months	0.015	0.005	0.003
	(0.009)	(0.004)	(0.002)
Agrees that interest in helping graduate students is important in my decisions t	0.237***	0.088***	0.049***
	(0.074)	(0.028)	(0.015)
Constant	-1.161***	-0.431***	-0.239***
	(0.360)	(0.134)	(0.074)
Observations	1531	1531	1531

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

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