2005 AIR DISSERTATION FELLOWSHIP PROPOSAL

Academic Entrepreneurship and Transformation in University Science: Status, Legitimacy, and Networks in the Diffusion of Private Science in the Academy

Data set of interest: National Study of Post-secondary Faculty (1987-88; 1992-93; 1998-99)

Fellowship Amount Requested: $15,000

Jeannette Colyvas
Doctoral Candidate
Stanford University School of Education
503 CERAS
Stanford, California 94305-3084
Phone 650.245.7593; Fax 650.725.7395
Email: colyvas@stanford.edu

Faculty Dissertation Director:
Walter W. Powell
Professor of Education
532 CERAS Building
Stanford, CA 94305-3084
Phone 650-725.7391; Fax 650.725.7395
Email: woodyp@stanford.edu

Authorized Institutional Representative:
Catherine Boxwell
Senior Contract Officer
Office of Sponsored Research
651 Serra Street
Stanford, CA 94305-4125
Phone 650.725.6864; Fax 650.723.1654
Email: boxwell@stanford.edu

_____ _____
Jeannette Colyvas, Principal Investigator Date

_____ _____
Walter Powell, Dissertation Director Date

_____ _____
Catherine Boxwell, Authorized Institutional Representative Date

2. PROJECT SUMMARY

This project examines patterns of entrepreneurship among academic scientists, addressing both a key empirical gap in the literature on commercialization of academic research and also policy concerns about the impact of private science on the quality of basic research, the public or open nature of the academy, and the priorities of universities.

Arguing that pecuniary incentives alone do not explain the adoption and spread of commercial science within the academy, this study examines critical social factors including status, networks, and legitimacy to suggest how these forces explain the increasing participation and 'enrollment' of academic scientists. The project analyzes the ways in which academic entrepreneurship has permeated into new fields and disciplines, at earlier stages of scientists' careers, as well as aspects of training and research. Specifically, this study examines: 1.) the factors that shape patenting patterns among scientists at varying stages of their careers; 2.) how the causal significance of these factors influences changes over time; 3.) the form and degree of involvement of faculty entrepreneurship; and 4.) how these features vary not only by scientific field and discipline, but also by institutional status.

Using the NSOPF survey for 1988, 1993, and 1999, the study tests a series of hypotheses that address faculty propensity and susceptibility to participating in entrepreneurial activities, such as patenting or owning a private business. Three critical aspects of the diffusion process are studied: 1.) status in terms of career stage or professional position within the university; 2.) network linkages to firms through funding or consulting; and 3.) the legitimacy of entrepreneurship within an academic setting. The proposed study sample will be a subset of the NSOPF data that includes all tenure-track or research faculty from doctoral granting institutions. The sample is limited to physical, life, computer, and engineering sciences. Descriptive statistics as well as logistic and multinomial logit models will be estimated for the analysis. Findings from the NSOPF project will be integrated into a broader conceptual model that includes a quantitative and qualitative case study analysis of Stanford University to address the issues of status, networks, and legitimacy, operationalized in the context of scientist collaboration networks and the impact of entrepreneurship on socially proximate scientists.

Findings from this study contribute to scholarship, policy, and practice in higher education. First, the study suggests the heterogeneity of the diffusion process, calling attention to not only scientists' intrinsic propensities to engage in

entrepreneurial practices, but also susceptibility in terms of the social, institutional, and organizational forces that shape their behavior. Second, by demonstrating how diffusion is a two-way, multidimensional process, this study calls attention to how some groups of scientist may be more influenced than others. Finally, this study fills an empirical gap by studying the scientists themselves as the unit of analysis, in contrast to most extant research that utilizes aggregate data on patents, licenses, and revenues. By examining individual characteristics related to research interests, productivity, professional work, and careers in the context of a range of commercial activities, this project gives voice to the creators and purveyors at the frontiers of science, and calls attention to the features of their activities that may be either most buttressed, or most tainted by commercial engagement.

3. TABLE OF CONTENTS

4. PROJECT DESCRIPTION

4.1 Statement of the Problem

In recent decades, university-industry interfaces appear to be changing in ways that suggest a blurring of boundaries between public (i.e. academic) and private (i.e. commercial) science. During the 1990's alone, university patenting increased two-fold, the number of university spin-off and start-up firms amounted to roughly 500, and the share of industrial funding of academic research nearly doubled (AUTM 2002; Cohen, et. al. 1998). A core feature of this change is that patenting and licensing of academic research has become a desirable and appropriate activity for research universities, which raises concerns among some commentators about shifting research priorities and corporate "capture" by private sector interests (Bok 2003; Slaughter and Leslie 1997; Slaughter and Rhoades 1996). Today, more than 200 universities have offices of technology licensing, compared to only 25 in 1980. The number of issued patents to universities has risen from 188 in 1969 to 2,436 in 1997, to 3,501 in 2002 (AUTM 2002). While the integration of patenting is well documented across universities, less is understood about the implications of proprietary science within universities as well as for individual scientists.

Recent scholarship underscores two puzzles with respect to the proliferation of technology transfer activities across universities. First, despite concerns over the impact on research, studies suggest that patenting does not reflect a pronounced shift in research orientation or scientific quality.[1] Rather, federal and industrial support appears to intermingle in common pursuits, most notably in the life sciences (Powell and Owen-Smith 2002). Second, despite patenting's overt association with financial opportunities, high profile breakthroughs and lucrative licenses are the exception, rather than the norm. Most technology transfer offices barely break even, and success is concentrated among a limited set of universities and patents (AUTM 2002; Owen-Smith 2000). Nevertheless, universities persist in their efforts to demonstrate their commercial acumen, arguably more as a symbolic gesture of legitimacy, rather than a means of supplementing waning income (Gumport 2002).

Thus, is there little cause for concern? Perhaps the ramifications or returns associated with patenting are not yet realized as universities become more experienced in identifying opportunities and navigating the complex landscape

[1] Studies thus far find little evidence that commercial interests have shaped the actual content of academic research (Mowery et. al. 1999). More recent studies have assessed patenting outcomes in terms of 'impact,' measured through citation counts, concluding that entry (Henderson, et. al. 1998; Mowery and Ziedonis 2001) or organizational learning (Mowery et. al. 2001), not shifting research priorities, explain patent impact patterns (Owen-Smith and Powell 2003).

of public and private science. Or, are the consequences less demonstrable and more diffuse, as commercial activities become more embedded in core features of the scientific missions of universities? Powell and Owen-Smith (2002) suggest possible second and third-order effects of commercial engagement within universities: "We think the most consequential effects…are likely to be unintended as changes ramify across a range of activities, from graduate training to career ladders to which fields are "hot" and who is able to collaborate with whom." I follow these concerns and draw attention to the processes that lead a commercial orientation to permeate into these aspects of scientific training and research. More specifically, I address: 1.) the factors that shape patenting patterns among scientists at varying stages of their careers; 2.) how the causal significance of these influences have changed over time; 3.) the form and degree of involvement of faculty scientists with the private sector (e.g. "faculty entrepreneurship"); and 4.) how these features vary by scientific fields and disciplines. In addition, I pursue questions about the impact of a growing entrepreneurial ethos on the socialization and training of academic scientists.

I seek to contribute to the literature on the commercialization of academic research by examining changes in patterns of academic entrepreneurship among scientists. I contend that understanding the implications of patenting depends on developing empirical knowledge of whether the increasing volume of patenting reflects a growth in the number of scientists participating in the commercialization of academic research or more intensive efforts by a relatively small number of established faculty. Research thus far points to the limited proportion of faculty who patent, compared to those who do not (Agrawal and Henderson 2002). Yet this research has been limited to a few departments and has not recognized the increasing entry of scientists into technology transfer activities. At Stanford University, of the 550 scientists who sought patents in 2000, roughly 50% were first time inventors. Given that returns to commercial efforts are low and uncertain, what mechanisms explain scientists' growing participation? And how do these factors vary over time and by field and discipline? I put forth a model that demonstrates the role of social proximity and contagion in the diffusion of entrepreneurial practices across individual scientists. I argue that material incentives and pecuniary influences alone are not sufficient to explain patenting patterns for individual scientists. I examine critical social factors including status, legitimacy, and networks. Furthermore, I contend that these social factors are the key to the participation and 'enrollment' of academic scientists in commercial efforts at increasingly earlier stages of their career.

I propose a study that utilizes the National Study of Post-secondary Faculty (NSOPF) over three time periods: 1987-88, 1992-93, and 1998-99. My objective is to integrate an analysis of this dataset into my dissertation, which also includes a detailed case study of academic entrepreneurship at Stanford University, a leading research university. For my dissertation, I have compiled a longitudinal dataset (1970-2003) of scientists at Stanford. I propose to construct a complementary dataset from the NSOPF: 1.) to analyze and test for a specific set of research questions and hypotheses; 2.) to apply and evaluate a conceptual model for addressing patterns of adoption of academic entrepreneurship; and 3.) to compare findings from the national survey population to my case-based population.

In the following sections I elaborate these three features of the proposal. I begin with a theoretical framework that includes relevant literature and provides the basis for the study and hypotheses. Next I describe a conceptual model for my dissertation that analytically distinguishes the propensity, susceptibility, and degree of engagement for academic entrepreneurship among scientists. I then describe the basis for comparison of the study population of NSOPF to the study population of my university case, emphasizing the statistical and analytic methods I will use for the NSOPF data. I conclude with a discussion of study implications, audience, and plans for dissemination. The overall study design of my dissertation integrates multiple research methods, which go beyond the scope of this proposal. I suggest, however, that much of the novelty and impact of this project relates to the ability to explore and test for core social features through multiple lenses, yet integrated within one conceptual model. Therefore, while the research questions, theoretical framework and conceptual model I put forth relates to the complete dissertation, I focus on how I propose to use the NSOPF data—specifically in the discussions relating to the testable hypotheses and statistical methods. I wish to emphasize that the opportunity to integrate the NSOPF portion of my study design into my dissertation and analytic framework would provide not only a significant and meaningful contribution to research in the field of higher education, but also an invaluable opportunity for my professional and scholarly development.

4.2 Theory and Hypotheses

The commercialization of academic research reflects the transfer of codified scientific research with intellectual property protection (e.g. patents) titled to universities through formal contractual agreements (e.g. licenses). Academic entrepreneurship refers to the engagement of faculty in the commercial application of basic research. Such efforts may include patenting academic research findings, but also activities that include ownership or risk associated with the commercialization of academic innovations developed or conceived within a university context (e.g. founding of firms or scientific advisory board membership). Recent scholarship emphasizes that entrepreneurship is not solely an intrinsic property of individuals, but is also influenced by social, cultural, and structural features of the institutional environment (Aldrich 2004; Hwang and Powell 2005; Thorton 1999). Entrepreneurship cannot be understood by abstracting from its social context, because it is always a permutation of that context. While commercialism takes many forms in institutions of higher education (Bok 2003), this study is concerned with academic science and therefore will limit the analysis to the physical, computer, engineering, and life sciences at research universities.

Scholarship on university-industrial interfaces and the commercialization of academic research underscores how the features that distinguish public sector (academic) and private sector (industry) science are less technical (i.e. what they do) than they are normative (i.e. why they do it). For example, Dasgupta and David (1994: 495) distinguish the realms of science and technology on the basis of "the nature of the goals accepted as legitimate within the two communities of researchers, the norms of behavior especially in regard to the disclosure of knowledge, and the features of the reward systems that constitute the fundamental structural differences." From this perspective, firms pursue private science through patenting, and universities support public science through publishing. Advancement in industry is based on pecuniary goals, while advancement in the academy is based on peer-review and priority of discovery (Merton 1973). Thus, increases in patenting and other entrepreneurial efforts on the part of academic scientists suggest a drift toward privatization of that which once was public, and thus a proprietary reward system.

Historians and economists of science highlight the long legacy of the university contribution to technical advance in industry (Geiger 1993; Rosenberg and Nelson 1994; Stephan 1996). This exchange took place, however, primarily through teaching and industrial development of applied science. Patenting within universities is a relatively recent

phenomenon. In the immediate postwar period through the 1970's, technology transfer from university to industry took place largely through publications, conferences, or informal relations with firms (e.g. consulting) (Geiger 1992). The passage of the Bayh-Dole Act in 1980, designed to stimulate American industry's ability to innovate, had a mobilizing effect on universities, signaling that technology transfer through patents was a desirable and appropriate activity for academic campuses (Mowery et. al. 1999).

Yet theory and evidence suggest that while patenting from the perspective of the university signaled conformity and responsiveness to national policy, this same activity from the perspective of scientists was more costly and disruptive to objectives of advancement and academic recognition. "[W]hat a society's laws endorse and prohibit might not correspond closely with what its members take for granted" (Carroll and Hannan 2000: 223), especially in the early stages of introduction. Institutional theory distinguishes between these two forms of legitimacy—the former, "socio-political legitimacy," which reflects endorsement at the level of policy or society, and the latter, "cognitive-legitimacy," which reflects an acceptance or 'taken-for-granted' status at the individual level (Aldrich and Fiol 1994; Baum and Powell 1995). This distinction is important for my research as I examine possible disjunctures between university and scientist views of patenting.

Most studies addressing the increasing commercialization of academic research draw on aggregate patent data from national data sources such as the United States Patent and Trademark Office, the NBER patent database, or the Association of University Technology Managers. While much information has been garnered with respect to the technical sources of growth in university patenting (Mowery et. al. 1999), the impact on scientific output (Mowery et. al. 2001), and the effect on competition and stratification among research universities (Owen-Smith 2003), very little work has been done that focuses on the activities, perceptions, and changing norms of scientists.[2] My project seeks to fill this gap in understanding by examining entrepreneurial patterns among scientists including: 1.) an 'at risk' sample of both "entrepreneurs" and non-entrepreneurs; 2.) a detailed set of variables, including features of individual scientists' research programs, work life, organization, and interactions with the private sector (e.g.

[2] The AIR-funded work of Bunker-Whittington (2004) is an exception in that she examines differentials in patenting behavior across sectors (university and the academy) and in terms of gender, using SESTAT data. Also, Stephan et. al. (2002) have a working paper comparing patenting and publishing among scientists utilizing the national survey of doctorate recipients.

through funding or consulting); 3.) the degree of involvement in entrepreneurial efforts; and 4.) an analysis of diffusion processes and how they relate to forms of legitimacy (i.e., socio-political or cognitive legitimacy).

As a baseline model, I suggest that status in terms of career stage or position within a university will likely influence adoption of a practice or norm, depending on its level of legitimacy. Recent theoretical work explores an established conjecture in sociology that conformity to a norm of appropriate behavior is highest in the middle, and lower at the top and bottom of a status hierarchy. Conversely, adoption of an 'illegitimate' practice is more likely to follow an inverted U-shaped curve: those who reside at the top and bottom of the status hierarchy do not experience strong pressures to conform and thus may deviate or differentiate themselves in ways that would be too risky for those of middle status (Philips and Zuckerman 2001). Therefore, faculty who seek tenure are more likely to conform to established norms and less likely to deviate from them, because their advancement depends on compliance to the 'rules of the academic game.' Faculty who have already received tenure are more secure in their positions and have more leeway to depart from established practices and adopt a behavior, such as patenting, that may be considered unusual, questionable, or inappropriate. Faculty who do not have a tenure-track appointment (e.g. adjunct, consulting, or part time faculty) are not subject to the same criteria in terms of research impact. Accordingly,

Hypothesis 1: *Faculty in a high status position within the university (i.e. post-tenure) will be more likely to take on entrepreneurial roles than faculty who are in a more 'middle' status position (i.e. pre-tenure). Faculty who are in a 'low' status position (i.e. non-tenure track research faculty) will also be more likely to take on entrepreneurial roles than 'middle' status (i.e. pre-tenure) faculty*.

Furthermore, the directional influence of status as an explanatory variable will vary as patenting becomes a more legitimated practice within scientific fields. I argue that the passage of the Bayh-Dole Act served as a first step marker of legitimacy for research universities. Endorsement and encouragement by the U.S. Congress is a strong signal of socio-political legitimacy. The adoption of academic entrepreneurship by scientists as a taken-for-granted activity reflecting cognitive legitimacy may have a different diffusion trajectory, however, based on either similar mechanisms with different degrees of influence, or entirely different factors pertinent to the institutional field or communities of the scientists themselves. Faculty in the 'middle' status positions will increasingly participate in academic entrepreneurship practices as they become institutionalized as a desirable and appropriate activity within their university or academic communities. Consequently,

Hypothesis 2: *As commercializing academic research becomes more legitimate, 'middle' status faculty (i.e. pre-tenure) will be more likely to participate in academic entrepreneurship activities (i.e. patenting), at similar levels with 'high' and 'low' status faculty.*

Networks also play a key role in the diffusion of new practices. Scientists with ties to industry are exposed to a domain where privatizing science is appropriate and expected. Scientists may interact with firms in a variety of ways, including consulting relationships, advisory relationships (e.g. scientific advisory board membership), sponsored research agreements, and technology licensing arrangements. Ties to industry are important because patenting or founding a company based on academic research findings requires 'how-to' knowledge, information, resources, or contacts to individuals who may provide such resources or help to promote the artifact of commercialization. The pilot interviews I have conducted with faculty scientists highlight how informal or project-based interactions with firms generate new ideas for research or ways of combining applied and basic problems with scientific tools and technologies that were previously considered separate. Faculty are able to 'triage' knowledge and ideas they gain from consultative interactions with companies and appropriate them into either dissertation problems for students, consulting projects for themselves, or short-term contract research projects. In previous research, I found that faculty licensing agreements frequently occur in the context of multiplex relations between faculty and companies—e.g. through scientific advisory board membership, equity holdings in firms, research collaborations, and gifts. (Colyvas and Goldfarb 2004). Scientists new to the practice of patenting research often report that the idea to patent an artifact of research came from a firm contact or interaction (Colyvas et. al. 2003). Hence,

Hypothesis 3: *Faculty with more ties to commercial entities (e.g. private consulting) are more likely to engage in academic entrepreneurship activities than those with few or no ties to companies.*

An additional network-based argument for entrepreneurial efforts on the part of faculty concerns the sources of support for funding research or pecuniary returns to licensed inventions. Empirical studies of the economics of higher education point to the growing share of research funding to universities from corporate sources (Cohen et. al. 1998). The amount of funding alone, however, is not the most pertinent feature that has changed. Rather, I argue that the transformation in the nature and form of this funding is particularly consequential. Case studies on the translation of university inventions into practice suggest that gifts of funding and equipment often coincide with licensing agreements (Colyvas et. al. 2002). Licensing agreements may indicate an on-going consultative or even collaborative relationship with scientists for both the transfer of the tacit aspects of an invention, and the further

incremental development and application of an innovation . Furthermore, licenses, especially exclusive ones, are highly associated with other forms of 'entrepreneurship,' such as firm founding and equity relationships with firms (Goldfarb and Colyvas 2003). Thus, funding from industry suggest not only transactional, but longer-term, on-going ties, which serve as a source of influence, information, and technical, social, and material resources that facilitate the commercialization of academic science. Thus, it follows that:

Hypothesis 4: *Faculty with industry funding are more likely to patent their research findings than those without industry funding.*

4.3 Study Design and Conceptual Model

The above hypotheses derive from a theoretical framework that places emphasis on core social factors related to status (as career stage and position in the university), networks (as scientist's linkages to industry), and forms of legitimacy (as socio-political and cognitive). In my broader dissertation design, I expand these theoretical constructs to address more of the relational aspects in social contagion. For example, I examine the role of relative status in scientist-to-scientist networks of collaboration (e.g. faculty to student) and examine the extent to which the susceptibility of diffusion permeates over time into new fields and earlier career stages. Furthermore, I examine the impact of the entrepreneurship of others on scientific peers--how features of success or failure by socially proximate entrepreneurs (e.g. faculty in the same department or discipline) make commercializing research findings more "infectious," or whether success in general (e.g. at the university) enrolls some scientists more than others over time. These features build on recent work in social contagion that calls attention to the spatial and temporal "heterogeneity" of processes in diffusion (Greve et. al., 1995, Strang and Tuma 1993). Put succinctly, this approach incorporates both propensities for adoption with the impact of adoption by others. Conceptually, the model also makes the further distinction of contagion effects by allowing the specification of: 1.) individual 'susceptibilities' to adoption, 2.) 'infectiousness' of prior adopters, and 3.) social 'proximity' of pairs of prior-potential adopters. In my dissertation, I use this model as an analytic framework for integrating both the qualitative and quantitative components of the study. The following table summarizes my study and qualitative research questions in the context of this heterogeneous diffusion framework. [3]

[3] To summarize the qualitative component of my study, I have been conducting a series of semi-structured interviews to examine the role of propensity, susceptibility, infectiousness, and proximity in academic entrepreneurship. I have been developing an interview database, selected from archived university bulletins and my Stanford database to sample scientists based on academic status, rank, experience in patenting, and by field or discipline (life, physical, computer, and engineering sciences). Whenever

Heterogeneous Diffusion Framework		
Dimensions of Diffusion	**Factors**	**Qualitative Research Questions**
Propensity to Adopt: *Why do some scientists commercialize research findings while others do not? What features of a scientist's position, status, or research program make them more likely to become involved in patenting and entrepreneurial efforts with their research? What influences make a scientist more susceptible to engaging in entrepreneurial efforts?*	Propensity (adopter's propensity to adopt net of any contagion via intrapopulation linkages)	How does research orientation influence the propensity to commercialize research findings? How do research resources (e.g. funding) influence the propensity to commercialize research? How does the propensity to patent vary by field or discipline?
	Susceptibility (adopters susceptibility to contagion)	Why do some scientists patent very little or not at all while others patent very often? Are there reasons why a scientist would be particularly pressed to or precluded from commercializing scientific findings? How do interactions with firms influence scientists' orientation toward patenting research (i.e. how does a potential adopter's interaction with firms influence a scientist's susceptibility to commercializing scientific research)?
Impact of Adoption by Others: *How do scientist peer networks influence and shape academic entrepreneurship? How does success at the university influence patenting for individual scientists? How does prior success or failure of colleauges influence the adoption of patenting?*	Infectiousness (infectiousness of a prior adopter for all adopters)	How is the commercialization of patenting research perceived? What are the reasons, rationales, and logics for academic entrepreneurship? Under what conditions or circumstances is patenting or licensing academic research perceived as successful or not successful? How does the success or failure of other academics influence the adoption of patenting behavior?
	Proximity (infectiousness of prior adopter for a specific adopter; the susceptibility of a potential adopter to a specific prior adopter)	How does collaboration (with a prior adopter) influence a scientist to commercialize academic research findings? Are strong affiliations or ties to a prior adopter more likely to influence a scientists orientation toward commercial science? How do ties to a successful inventor influence an adopters liklihood to engage more closely with industry? How does a colleague's relative status (i.e. professor to graduate student) influence the 'infectiousness' of the prior adopter or the 'susceptibility' of the potential adopter? How does the perceived experience or outcome of a colleague's commercial interaction influence one's potential for patenting research findings?

As a statistical method, the heterogeneous diffusion model requires consistent data collected over time, which is not suitable for the NSOPF survey frame, since it was collected in three cycles. While I am exploring the applicability of this statistical model for my Stanford data, with the NSOPF data I propose to analyze the features of propensity and susceptibility where my review of the codebook suggests that the variables are rich sources for testing my hypotheses. With my Stanford data, I investigate the social contagion processes and effects (i.e. the impact of adoption of others in the table above) where the scientist collaboration networks are especially comprehensive.

4.4 Data, Methods, and Analysis

Stanford University is among the earliest and most successful universities to engage in active commercialization efforts. With the combination of high quality science, a long legacy of industrial interactions, and early commercial

possible, I have been interviewing full teams of inventors where there are higher and lower status scientist inventors (e.g. faculty with students) in order to examine influence and socialization processes.

breakthroughs, such as the recombinant DNA gene splicing technique, Stanford is considered a model for success throughout the world among technology transfer professionals. I have compiled a relational database of invention disclosure and licensing data from Stanford from 1970-2003. Invention disclosures are documents that represent events of submission of a research finding to the university with the intention of commercial transfer through some form of intellectual property protection (e.g. a patent or copyright), and a licensing agreement to another organization. From these sources, information such as inventor names, inventor academic position or status (e.g. faculty, student, staff), date of invention, and terms and success of transfer are available. The benefits of this data for exploring the role of social contagion and diffusion include: 1.) more detailed information on scientist collaboration networks than is available from patent co-inventor databases; 2.) measures of both the success and failure of technology transfer (i.e. whether or not a patent is granted or a licensee is identified); and 3.) inventor department and program affiliations. This information provides a rich dataset for exploring the rate and direction of diffusion of proprietary science, enabling analysis of the implications for how this activity permeates into new departments within the university and into early career stages of scientists (e.g. students and pre-tenured faculty). There are, however, limitations. First, the dataset does not include a set of scientists who have not submitted an invention disclosure. Second, core features of a scientist's overall research program (e.g. size of research program, funding sources, allocation of time, and external consulting activities) are not systematically observable for the sample population for the full time-period. Finally, additional exposure to industry through consulting and research support are not available.

The NSOPF asks a series of questions that provide a window into these features of academic entrepreneurship and diffusion that compliments the Stanford data and allows for a deeper examination and analysis of the propensity and susceptibility features in the context of status, networks, and legitimacy that I described earlier. First, the NSOPF dataset asks detailed questions about salary, compensation from non-university sources (including royalties and outside consulting), allocation of time, sources and level of research funding, and academic 'output' including patents, publications, and software products. It also asks a number of questions relating to the fields and disciplines of academic research, biographical background, and perceptions of research orientation (e.g. basic or applied). Such information provides not only a rich set of independent variables gauging the propensity and susceptibility of patenting, but will also allow me to explore composite and more meaningful measures for the degree of engagement

in academic entrepreneurship, and potentially explore variation by cohort with the data on age and experience. The table below elaborates on the architecture of this study in the context of both datasets.

Heterogeneous Diffusion Framework

Dimensions of Diffusion	Factors	Quantitative Variables	Stanford Dataset	NSOPF Dataset
Propensity to Adopt: *Why do some scientists commercialize research findings while others do not? What features of a scientist's position, status, or research program make them more likely to become involved in patenting and entrepreneurial efforts with their research? What influences make a scientist more susceptible to engaging in entrepreneurial efforts?*	Propensity (adopter's propensity to adopt net of any contagion via intrapopulation linkages)	Size of research program	No	Yes
		Research orientation	No	Yes
		Quality of research	No	Limited
		Field or discipline	Yes	Yes
	Susceptibility (adopters susceptibility to contagion)	Status classification	Yes	Yes
		Level of legitimacy	Yes	Yes
		Ties to industry	Limited	Yes
		Funding from industry	Yes	Yes
Impact of Adoption by Others: *How do scientist peer networks influence and shape academic entrepreneurship? How does success at the university influence patenting for individual scientists? How does prior success or failure of colleauges influence the adoption of patenting?*	Infectiousness (infectiousness of a prior adopter for all adopters)	Prior success of technology licensing program	Yes	No
		Prior inventor success or failure of a high-profile innovation	Yes	No
	Proximity (infectiousness of prior adopter for a specific adopter; the susceptibility of a potential adopter to a specific prior adopter)	Organizational proximity (i.e. same departmental affiliation)	Yes	No
		Prior adopter's relatiove position (e.g. faculty or student) or career (e.g. tenure) status	Yes	No
		Prior adopter's ties to firms	Yes	No
		Prior adopter's success	Yes	No
		Perceived cultural/structural similarity to prior adopter (e.g. measure based on disciplinary proximity and career stage)	Yes	No

The NSOPF surveys faculty and instructional staff at institutions of higher education in the U.S., allowing for detailed comparisons at both the individual and institutional levels. The survey has been conducted in three cycles: 1988, 1993, and 1999. For my study, I propose to extract respondents who hold tenure track or research faculty

appointments in a scientific field or discipline at a research university. My objective is to identify a study sample that is both similar in key respects to the Stanford sample, but adds variation in terms of institutional status. In addition, the NSOPF provides a complimentary set of scientists who do not engage in commercial activities (i.e. do not indicate that they hold a patent, own a business, or consult). While there have been a few modifications to the survey over the three cycles, the core questions of interest are included.[4] For example, questions about patenting (NSOPF: 99, question #9), compensation (NSOPF: 99, Section E), and allocation of time (NSOPF: 99, question #31) for professional activities have remained consistent. Also, although the 1993 and 1999 cycles include a broader sample of all Title IV participating institutions, my study is concerned with four-year research universities and therefore I have adequate coverage in 1988. My aim is to obtain a license for the restricted use faculty data file, which includes a more thorough set of derived variables.

The dependent variable for my analysis is entrepreneurial effort. I will operationalize this in two ways: first, as a discrete outcome of whether or not a faculty member reports holding a patent; and second, as a composite measure including other indicators of entrepreneurial effort (e.g. based on allocation of time, whether owns a business, consults, patents). I will also explore the construction of a categorical variable reflecting degree of engagement in entrepreneurial activity based on composite measures (e.g. has patents; has some other indicator of entrepreneurial involvement such as owns a business; has some combination of entrepreneurial indicators, and has no entrepreneurial involvement). I will begin my analysis with descriptive statistics and a graphical analysis of entrepreneurial differentials across time periods, scientific fields, status of institutions, and faculty status. A binary logistic regression model will be estimated for each model where the outcomes are discrete. For the polytonomous dependent variable, I will estimate a multinomial logit model. The independent variables I will utilize size of research program, research orientation (basic/applied), quality of research, status classification (career stage or position in institution), industry ties (yes/no), and industry funding (yes/no). I will include control variables for institution's status, scientific field or discipline, and demographic variables such as race/ethnicity and gender. I will also run the models separately for each survey cycle.

[4] I note, however, that the 1993 and 1999 survey cycles have a slightly more expansive definition of faculty, including those individuals who do not have a specific teaching responsibility in their job description.

4.5 Dissemination Plan

My aim is to present work in progress at the upcoming Association for Higher Education conference in Fall 2005 and results at the American Educational Research Association in Spring 2006. If accepted, I will present this study to the annual AIR Forum in New Orleans. Other possible venues for presentation and scholarly discussion include the 2006 meetings of the Academy of Management and the American Sociological Association. My objective is to develop a number of publications and I plan to submit chapters of my dissertation to high quality scholarly journals. Eventually, I want to turn my dissertation into a book published by a good university press. I will provide institutional profile and analysis to the Stanford University Office of Technology Licensing and to the Dean of Research and graduate policy. I have been participating in a Bay Area intellectual property forum that includes faculty, administrators, and managers from both university and industry and meets informally once a month. I will present findings from my study at the annual IP forum in 2006.

4.6 Significance of Research, Policy Relevance, and Target Audience

This project fills several gaps in the existing literature. First, almost all research on university commercialization uses aggregate data about patents, licensing, and revenues. My work is different in that my unit of analysis is individual scientists, and I examine their research interests, productivity, careers, and mentoring activities, in addition to the range of their commercial involvement. There is immense research and policy interest in the commercial impact of American science. It seems high time that these discussions are informed by analyses of the behaviors and opinions of the actual scientists.

Conceptually, this project draws on and integrates research on higher education, institutional analysis, and network analysis—a combination that is unusual and, I believe, fresh and valuable. My adaptation of the heterogeneous diffusion framework to the likelihood of commercial involvement by scientists is novel, and will, I hope, be an important contribution to the growing social science literature that recognizes that diffusion is a two-way, multi-dimensional process. This conceptual contribution not only adds agency and voice to the scientists I study, but enriches analyses of diffusion and contagion by showing how the very object being diffused transforms as it spreads, permeates into new fields and disciplines, and enrolls scientists earlier in their career.

The policy implications are most pertinent, given the explosion of commercial science in the last decades and what little is known empirically about its effects on laboratories and scientific training. By addressing the role of status (as career stage and position in the university) and network relationships with scientific peers and industry, I call attention to the possible second and third order effects of commercial science that have not yet been assessed. For example, if the conjectures are true that: 1.) the most valuable scientific accomplishments are made early in one's career, and 2.) that close interaction with industry compromises open dissemination or pulls research toward a more applied orientation, then a spread of commercial science into graduate, post-doc, or pre-tenure training suggests that the most profound impact of industry reach on the quality of science is yet to come. My research not only underscores the extent to which our measurable results may be premature, but also calls attention to mechanisms that shape future generations of scientists. It is my belief that findings and insight from this study will call attention to areas where more meaningful policy attention and intervention may be directed.

5. REFERENCES CITED

Agrawal, A. & Henderson, R. (2002). Putting Patents in Context: Exploring Knowledge Transfer from MIT. *Management Science*, 48, 44-61.

Aldrich, H. E. (2004). Entrepreneurship. In R. Swedberg & N. Smelser, (Eds.). *Handbook of Economic Sociology*. Princeton: Princeton University Press and Russell Sage Foundation.

Aldrich, H. E. and Fiol, C. M. (1994). Fools Rush In? The Institutional Context of Industry Creation. *Academy of Management Review*, 19, 645-670.

Association of University Technology Managers (2002). *Technology Licensing Survey*.

Baum, J. A., & Powell, W. W. (1995). Cultivating and Institutional Ecology of Organizations: Comments on Hannon, Carroll, Dundon, and Torres. *American Sociological Review*, 60 (4), 529-538.

Bok, D. (2003). *Universities in the Marketplace: The Commercialization of Higher Education.* Princeton, NJ: Princeton University Press.

Bunker-Whittington, K. (2004). Employment Sectors as Opportunity Structures: The Effects of Location on Male and Female Scientific Dissemination**.** Proposal Selected by the Association for Institutional Research.

Carroll, G.and Hannan, M. (2000) *The Demography of Corporations and Industries.* Princeton, NJ: Princeton University Press.

Cohen, W., Florida, R., Randazzese, L., & Walsh, J. (1998). Industry and the Academy: Uneasy Partners in the Cause of Technological Advance. In Noll, R. (Ed.) *Challenge to Research Universities.* Washington, DC: Brookings Institution Press.

Colyvas, J. & Goldfarb, B. (2003). Stanford Inventor Survey. Unpublished working paper.

Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R., Rosenberg, N., & Sampat, Bhaven. (2002). How Do University Inventions Get Into Practice? *Management Science*, 48, 61-72.

Colyvas, J., Gelijns, A. & Rosenberg, N. (2003). Intellectual Property Rights and the Rise of Academic Medical Centers. Forthcoming in Grandstrand, Ove, ed. *Economics, Law and Intellectual Property*. Gothenberg, Sweden: Kluwer Academic Publishers.

Dasgupta, P., & David, P. (1994). Toward a New Economics of Science. *Research Policy*, 23(5), 487-521.

Geiger, R. (1992). The Ambiguous Link: Private Industry and University Research. In W. E. Becker & D. R. Lewis (Eds.), *The Economics of American Higher Education* (265-97). Norwell, MA: Kluwer.

Geiger, R. (1993). *Research and Relevant Knowledge: American Research Universities Since World War II*. Oxford University Press.

Goldfarb, B. & Colyvas, J. (2003) Do Strong Property Rights Inspire Academic Entrepreneurship? Unpublished manuscript.

Greve, H. R., Strang, D. Tuma, N. B. (1995). Specification and Estimation of Heterogeneous Diffusion Models. *Sociological Methodology*, 25, 377-420.

Gumport, P., (2002). Universities and Knowledge: Restructuring the City of Intellect. In Steven, B. (Ed.). *The Future of the City of Intellect.* Stanford, CA: Stanford University Press.

Henderson, R., Jaffe, A. B., & Trajtenberg, M. (1998). Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965-1988. *The Review of Economics and Statistics*, 80 (1), 119-127.

Hicks, D., and Katz, J.S. (1996). Science Policy for a Highly Collabortive Science System. *Science and Public Policy*, 23, 39-44.

Hwang, H. & Powell, W. (2005). Institutions and Entrepreneurship. In Alvarez, S., Agrawal, R. and Sorenson, O. (Eds.). *Handbook of Entrepreneurship Research.* New York: Springer.

Jensen, R. & Thursby, M. (2001) Proofs and Prototypes for Sale: The Licensing of University Inventions. *American Economic Review.* 91, 240-259.

Merton, R. K. (1973). *The Sociology of Science.* Chicago, IL: University of Chicago Press.

Mowery, D., Nelson, R., Sampat,B. & Ziedonis, A. (1999). The Effects of the Bayh-Dole Act on US University Research and Technology Transfer. In Lewis Branscomb, ed. *Industrializing Knowledge.* Cambridge, MA: MIT Press.

Mowery, D. & Sampat, B. (2001). University Patents, Patent Policies, and Patent Policy Debates: 1925-1980. *Industrial and Corporate Change*, 10, 781-814.

Mowery, D. & Ziedonis, A. (2001). The Geographic Reach of Market and Non-Market Channels of Technology Transfer: Comparing Citations and Licenses of University Patents. NBER Working Paper No. W8568.

Owen-Smith, J. (2003). From Separate Systems to a Hybrid Order: Accumulative Advantage Across Public and Private Science at Research One Universities. *Research Policy*, 32, 1081-1104.

Owen-Smith, J. (2001) New Arenas for University Competition: Accumulative Advantage in Academic Patenting. In Croissant, J. & Restivo, S. (Eds.). *Degrees of Compromise: Industrial Interests and Academic Values.* New York: SUNY Press.

Phillips, D. & Zuckerman, E. (2001). Middle-Status Conformity: Theoretical Restatement and Empirical Demonstrations in Two Markets. *American Journal of Sociology*, 107 (2), 379-429.

Powell, W. & Owen-Smith, J. (2002). The New World of Knowledge Production in the Life Sciences. In Brint, S. (Ed). *The Future of the City of Intellect: The Changing American University.* Stanford, CA: Stanford University Press.

Rosenberg, N. & Nelson, R. (1994). American Universities and Technical Advance in Industry. *Research Policy,* 23, 323-348.

Rosenberg, N., Goldfarb, B. & Colyvas, J. (2003). Statistical Analysis of Stanford Inventive Activity. Report to Stanford University Dean of Research.

Slaughter, S. & Leslie, L. (1997). *Academic Capitalism: Politics, Policies and the Entrepreneurial University.* Baltimore: Johns Hopkins University Press.

Slaughter, S. & Rhoades, G. (1996). The Emergence of a Competitiveness Research and Development Policy Coalition and the Commercialization of Academic Science and Technology. *Science, Technology, and Human Values.* 21 (3), 303-339.

Stephan, P.E. (1996). The Economics of Science. *Journal of Economic Literature*, 34 (3), 1199-1235.

Stephan, P., Gurmu, S., Sumell, A.J. & Black, G. (2002). Patenting and Publishing: Substitutes or Complements for University Faculty? Prepared for presentation at NBER Higher Education Meeting. May 3, 2002.

Strang, D. & Tuma, N. (1993). Spatial and Temporal Heterogeneity in Diffusion. *American Journal of Sociology*, 99 (3), 614-639.

Thornton, P. (1999). The Sociology of Entrepreneurship. *Annual Review of Sociology*, 25, 19-46.

6. BIOGRAPHICAL SKETCHES

Jeannette Colyvas

I am a fourth year doctoral candidate in the Stanford University School of Education, currently pursuing an M.A. in sociology and a PhD in academic policy analysis/higher education. I speak four languages (English, Spanish, Japanese, and Greek), hold a B.A. in history from the University of California at Los Angeles, and an M.A. in East Asian Studies from Stanford University. My policy and empirical interests include the role of research universities in the organization of R&D in the US and abroad; academic entrepreneurship and the commercialization of university research; and boundary formation and change in university-industrial interfaces. My current work explores the relationship between institutions and networks in scientific collaborations. I also study diffusion processes and how theorized models of entrepreneurship emerge, replicate and even fail as they are shared and transferred.

I have research experience in interdisciplinary settings, working with scholars and practitioners in the social and policy sciences. From 1998-2000, I collaborated with Nathan Rosenberg (Professor of Economics) and Annetine Gelijns (Columbia University Professor of Medicine) studying the role of academic medical centers in technological innovation. This project culminated in two publications: 1.) Colyvas, Jeannette, Annetine Gelijns, and Nathan Rosenberg. 2003 "Intellectual Property Rights and the Rise of Academic Medical Centers. In Grandstrand, O., (Ed.) *Economics, Law and Intellectual Property.* Gothenberg, Sweden: Kluwer Academic Publishers.; and 2.) Colyvas, Jeannette, Michael Crow, Annetine Gelijns, Roberto Mazzoleni, Richard Nelson, Nathan Rosenberg, and Bhaven Sampat. 2002. "How do University Inventions Get Into Practice?" *Management Science 48:* 61-72.

In 2000, I was asked to work on a two-year project for Stanford University's office of the Dean of Research to study the role of the university in the Silicon Valley. The project included a faculty team of two economists, an historian of science and technology, a distinguished policy practitioner, and a technology licensing manager. My role in this project was to conduct a statistical and case-based analysis on Stanford's historical and contemporary inventive activity. A core feature of this project included the design, execution, and analysis of a survey to Stanford inventors on their role in the development and diffusion of their research. This project resulted in two reports to the office of the Dean of Research, which are currently being edited for publication as a book. I have also co-authored three

scholarly working papers as a result of this project, which are currently being revised for submission to journals: 1.) Colyvas, Jeannette and Brent Goldfarb, "Findings from a Survey to Stanford University Inventors;" 2.) Goldfarb, Brent and Jeannette Colyvas, "Tacit Knowledge, Uncertainty, and Start-ups;" and 3.)Goldfarb, Brent and Jeannette Colyvas, "Strong Property Rights and Academic Entrepreneurship." In 2002, I was awarded a fellowship through the Stanford-Columbia Consortium on Pharmaceutical Innovation and I am currently working with my advisor, Walter W. Powell, on how patterns of relationships among academic scientists shape the kinds of scientific innovations that are pursued and developed.

I have recently presented my research at a number of conferences and have shared my work in progress with both scholars and practitioners. In October 2004, I was selected to participate in the annual Association for Higher Education Graduate Student Pre-Conference on Higher Education Policy. In November, I presented preliminary dissertation findings on my Stanford Case Study at the Stanford-Berkeley Mini-Conference on University-Industry Interfaces. In December 2004, I presented a chapter to my dissertation on "Academic Entrepreneurship and Transformation in University Science" in Uppsala, Sweden at a Symposium on "Science and Creation of Value Symposium." I have also submitted an abstract to the European Group for Organizational Studies annual meeting for June 2005 in Berlin, Germany. I periodically present my work in progress at the Stanford Office of Technology Licensing, and participates in a monthly "Basic IP" group that is organized by Hewlett Packard and includes 10-15 faculty administrators and industry managers from universities and companies in the Silicon Valley-Bay Area.

I continue my training in research methods and analysis. I have completed three statistics courses including regression and analysis of variance in the School of Education, a course on introductory epidemiological methods and statistics in the School of Health Policy, a course on network analysis in the Department of Sociology, and plan to attend a summer training institute in multivariate analysis this summer. As mentioned above, I have considerable experience conducting and analyzing surveys, and much experience working with archival materials.

Walter W. Powell

Walter W. Powell is Professor of Education and (by courtesy) Professor of Organizational Behavior, Sociology, and Communication at Stanford University. He is also an external faculty member at the Santa Fe Institute. At Stanford, he is Director of the Scandinavian Consortium on Organizational Research. He joined the Stanford Faculty in July 1999, after previously teaching at the University of Arizona, MIT, and Yale. He has been a fellow at the Center for Advanced Study in the Behavioral Sciences and has been a visiting faculty member several times at the Institute for Advanced Studies in Vienna, and the Santa Fe Institute. Professor Powell works in the areas of organization theory and economic sociology. He is co-author of *The Culture and Commerce of Publishing* (1983), an analysis of the transformation of book publishing from a family-run, craft-based field into a multinational media industry, and author of *Getting into Print* (1985), an ethnographic study of decision-making processes in scholarly publishing houses. He has been involved in a number of studies of non-profit organizations, ranging from public television to university presses to art museums to higher education. He edited *The Nonprofit Sector* (1987, referred to by reviewers as "the Bible of scholarship on the non-profit sector"), and is currently working with Richard Steinberg on a second edition of the handbook. Powell is also co-editor with Elisabeth Clemens of *Private Action and the Public Good* (1998).

Professor Powell is most widely known for his contributions to institutional analysis, beginning with his article, with Paul DiMaggio, "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields" (1983, also translated into French, German, Italian, Japanese, and Spanish) and their subsequent edited book, *The New Institutionalism in Organizational Analysis* (1991, translated into Spanish and Italian). This line of work continues in a forthcoming edited book, *How Institutions Change*.

Powell is currently engaged in research on the origins and development of the commercial field of the life sciences. He has authored a series of papers on the evolving network structure of the biotechnology industry. This line of work continues his interests in networks as a form of governance of economic exchange, first developed in his 1990 article, "Neither Market Nor Hierarchy: Network Forms of Organization," which won the American Sociological Association's Max Weber Prize and has been translated into German and Italian. Powell and his research collaborators have developed a longitudinal data base that tracks the development of biotechnology worldwide from

the 1980s to the present. In support of this work, he has received three National Science Foundation grants, and research funding from both the Hewlett and Merck Foundations. His former student, Jason Owen-Smith (now on the faculty at the University of Michigan) received an AIR grant in 1998.

Powell is chair of the executive committee of the Board of Directors of the Social Science Research Council. At Stanford, he is a member of the Editorial Board of the University Press, a faculty affiliate of the Center for Social Innovation at the Graduate School of Business, and serves on the governing board of the France-Stanford program.

7. PROPOSED BUDGET AND JUSTIFICATION

Category	**Requested Funds**
Personnel Salaries	
Jeannette Colyvas—12 months @ $1,100 month	$12,720
Including benefits at 3.4%	$433
Travel	
Domestic (AIR Annual Forum, Annual Meeting of the Association of Higher Education)	$1,200
Other Direct Costs	
Materials and Supplies (Printing, Photocopying, Research Related Books and Software, Dissertation Dissemination)	$647
Total Amount of Award	$15,000

I request funding for salary (stipend), travel, and materials and supplies. The requested stipend funding includes 3.4% benefits for the duration of the project, and covers approximately half of my monthly support. I request support to travel to two conferences, including the annual AIR meeting. Other direct costs include printing, photocopying, and dissemination of my dissertation results.

8. CURRENT AND PENDING SUPPORT

I am currently serving as a teaching assistant in the School of Education for winter quarter 2004-05. I have applied for renewal for a fellowship in the amount of $10,000 through the Stanford-Columbia Consortium on Pharmaceutical Research that would supplement my support from April-June 2005. I currently do not have support for the academic year 2005-06.

9. FACILITIES, EQUIPMENT, AND OTHER RESOURCES

Laboratory: The School of Education houses a PC classroom and a multi-media lab that may be used for research, in addition to the lab spaces of the faculty.

Computer Facilities: Stanford is extremely well equipped with over 100 computer laboratories across campus open student and faculty use. Meyer Library, for example, includes multiple floors of technology (and consultants) available to faculty to work with analog and digital video, as well as other media. The current project will reside in the School of Education, which is connected to the campus backbone by fiber optic cable. All faculty and students have 100mpbs connections to the Internet with the potential for greater switching speeds. There are both PC and Apple computer labs with 20+ stations and peripherals, along with multiple servers in the Center for Educational Research at Stanford (CERAS).

Other Facilities: Stanford University and the School of Education have earmarked substantial existing and to-be-raised funds to convert the first floor of the CERAS building into a Center for Learning and Technology.

10. SPECIAL INFORMATION AND SUPPLEMENTARY DOCUMENTATION

None.