MEASURES, METRICS, AND MYOPIA: THE CHALLENGES AND RAMIFICATIONS OF SUSTAINING ACADEMIC ENTREPRENEURSHIP

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INTRODUCTION

Contemporary life is replete with all manner of rankings, metrics, and benchmarks (Power, 1997; Espeland & Stevens, 1998). From J.D. Power evaluations of cars to Zagat restaurant reviews to US News and World Report ratings of colleges and universities, modern life seems to be deep in the grip of assessment and evaluation. In the early decades of the twentieth century, the introduction of scientific management transformed the workplace, altering relations between labor and capital, and embedding control over the nature and pace of work into the technical organization of production (Edwards, 1979; Shenhav, 1995). In a similar fashion, the current embrace of rankings may reflect a new “Taylorism,” as metrics have the capacity to not only reorder the social institutions they are purported to assess, but also provide a patina of objectivity, especially for the uninitiated.

We analyze the practice of technology transfer to examine the forms of engagement and types of comparisons associated with academic entrepreneurship. University technology transfer is a fertile site, both empirically
and theoretically, as its development has been fairly rapid and widely articulated, allowing us to examine the nature of its institutionalization. We also hope to contribute to public policy discussions, by examining whether academic entrepreneurship has been beneficial to the universities, the knowledge economy, and the advancement of science.

Our data are drawn from Stanford University, a much-studied setting because of its openness to researchers and its status as a pioneer in technology transfer (Mowery, Nelson, Sampat, & Ziedonis, 2004; Kenney & Goe, 2004; Colyvas, 2007a). Rather than focusing exclusively on Stanford faculty, as most researchers have, we also examine invention disclosures and patenting by PhD students in a high-profile basic life science department. To the extent that we are able, we follow these students after receipt of their PhD as they move into jobs in the academy or industry. Focusing on the inventive behavior of students provides a different metric from criteria commonly used to evaluate university entrepreneurship. This lens is valuable as it offers insight into how practices may or may not become sustainable and reinforcing, allowing us to gauge whether academic entrepreneurship has become deeply institutionalized. From the viewpoint of public policy, examining the activities of PhD students pre- and post-graduation also permits discussion of the social and economic consequences of engagement in commercial science.

We begin with a discussion of the conceptual issues raised by the widespread use of benchmarks. We consider efforts at evaluation in terms of the joint processes of commensuration and reactivity (Espeland & Sauder, 2007). Commensuration refers to the transformation of qualitative distinctions into quantitative measures, where difference is expressed as magnitude rather than character (Espeland & Stevens, 1998). Reactivity occurs when attention to rankings and metrics shapes perception and becomes built into organizational behavior. We next review the recent historical development of university technology transfer. We have previously cautioned against the widespread tendency to emulate universities that either by virtue of history or propitious circumstances have track records that are not readily attainable by others (Powell, Owen-Smith, & Colyvas, 2007). To better understand why institutions might benchmark themselves in terms of metrics that are poorly suited to their local circumstances, we discuss the diverse means by which entrepreneurial activities become weakly or deeply institutionalized. Our setting and data are introduced next. We then present our findings. The implications follow, along with commentary on alternative indicators for measuring entrepreneurial science and discussion of their implications for open science.
From our perspective, the key challenges with respect to evaluating technology transfer stem from the undue effort at copying successful cases and a failure to develop more original and local measures that are distinctive to particular institutions. Universities, in absorbing these new benchmarks for technology transfer, have overlooked important features that make attaining these rankings sustainable, such as the degree of integration of entrepreneurial practices into early-career science. Furthermore, many of the second- and third-order effects of wholesale adoption of these practices may be neglected, such as the deflection of new talent into non-research, industry careers. We argue that an examination of alternative indicators of the extent to which entrepreneurial practices have taken hold, become sustainable, and influence graduate student careers, provides more purchase for universities in the context of their local environments.

**MEASUREMENT AND REACTIVITY**

Efforts at developing social and economic metrics are consequential in a number of powerful, if sometimes invisible and unintended, ways. The benchmarks that an organization deploys serve to focus its attention and allocation of resources. In a classic study of employment agencies, Blau (1954) demonstrated that whether the measure was number of clients processed or number of jobs obtained by clients had a huge effect on how work was conducted. Benchmarking also compresses a wide array of information into a simple number that purports to compare very different entities with one another. Consider the surprise and incongruity that accompanied the reception of a lofty Zagat score by a Brooklyn storefront restaurant, an evaluation that was equivalent to those received by Manhattan’s temples of haute cuisine (Fabricant, 2003). In contrast, consider how the rankings of top-tier law schools suggest there are significant, measurable differences among a cluster of comparable elite schools (Espeland & Sauder, 2007). In the former case, similar scores were perceived as inexplicable, while in the latter, minute differences are made to seem much more significant than they actually are.

Efforts at benchmarking and commensuration may also provoke loose coupling, in which “front stage” organizational representation stands in contrast to the “backstage” reality (Goffman, 1967; Meyer & Rowan, 1977). In early research on loose coupling, scholars found that the core activities of an organization were commonly buffered from close inspection, and organizations often engaged in a type of ceremonial conformity that was
detached from their core activities. In today’s more transparent world, such buffering is much more difficult and organizational actions are subject to greater scrutiny. Nevertheless, in the current environment of national and international rankings of schools and universities, all manner of minor tweaks and/or strategic gaming can alter ratings and reputations, even though these steps have little consequence for education.

Finally, the production of metrics can strip practices of the context in which they were developed and elaborated, and turn them into free-floating measures that appear to be devoid of the struggles and accomplishments that generated them in the first place. In the late 1980s and 1990s, the global auto industry was obsessed with the secret recipe for lean production that was developed and honed by Toyota (Cusumano, 1985; Womack, Jones, & Roos, 1990; Fruin, 1994). But the “Toyota model” proved difficult to transplant to a U.S. setting where on-the-job training was largely neglected and components were routinely outsourced on the basis of price. Similarly, the Toyota production system did not fare well in Europe either, with its system of works councils, and high-skill employees with strong union representation (Berggren, 1992). A decade of struggle, contention, and unsuccessful emulation ensued, with millions of dollars spent and thousands of jobs lost. Over time, as auto manufacturers recognized the difficulties of copying one another, an amalgam of global best practices emerged, which were crafted onto existing models of automaking (Macduffie, 1995).

University technology transfer and academic entrepreneurship are hardly immune from the proliferation of metrics. Of course, the generation of licensing income is the most touted benchmark. Witness the recent December 14, 2007 article in The Chronicle of Higher Education with the caption: “3 More Universities Join $10-Million Club in Annual Revenue From Licensing Inventions” (Blumenstyk, 2007). Some universities with a strong focus on local economic development choose to highlight the number of start-up companies formed, with the view that these represent jobs and services contributed to the regional economy. Still others emphasize patenting as a measure of a university’s contribution to commercial science. The number of licenses signed with companies is another metric, and the number of new products that enter the marketplace is yet another. While all of these benchmarks are comparable across universities, they are crude in several respects. Attention to income or start-ups suggests that technology transfer officials have the ability to pick winners, a prospect that is rather unlikely. An emphasis on patenting generates counts but does not capture linkages to the economy. Moreover, extensive patenting means that universities are asserting proprietary claims to more areas of basic scientific
research. These various efforts at counting "productivity" have provoked criticisms by some champions of entrepreneurship, who decry that universities spend too much time documenting "success" and have failed to move new university-developed technologies "out the door" into the broadest possible markets quickly (Kauffman Foundation, 2007).

Other groups have argued that technology transfer should evince a commitment to improving human welfare by promoting widespread access to university research and increasing attention to diseases that disproportionately affect the poor. A UC-Berkeley tech transfer officer, Carol Mimura, reflects on how the choice of metrics shapes practice: "If you measure success only by the amount of royalties and fees you bring in, then your licensing practices will reflect that. If you measure success in terms of social impact or awareness and you count things such as gifts, research collaborations, global impact and boost to your reputation, it changes your orientation" (Check, 2006, p. 413). Efforts are currently underway at some tech transfer offices (TTO's) to champion socially responsible licensing, and to better assess social impact. Whether the aim is to maximize economic or social value, or both, the tension of generating meaningful categorical and numerical benchmarks persists. Given the diversity of institutions of higher education, their strengths and advantages in some areas over others, the puzzle remains whether existing metrics focused on magnitude can capture the real social impact of technology transfer or whether more local, contextualized indicators can be harnessed.

TECHNOLOGY TRANSFER AT U.S. UNIVERSITIES

University technology transfer has been much studied in recent years, and there are several good summaries of the scholarly literature (Phan & Siegel, 2006; Rothaermel, Agung, & Jiang, 2007). In addition, the Association of University Technology Managers (AUTM) produces a comprehensive annual survey chronicling the activities of U.S. universities and hospitals. We join these discussions with a particular lens, drawing on research that analyzes how organizational structures and practices become institutionalized (Meyer & Rowan, 1977; DiMaggio & Powell, 1983). Research in this vein has analyzed affirmative action procedures in U.S. corporations (Edelman, 1992), human resource management policies (Dobbin & Sutton, 1998), the expanding ranks of chief corporate officers (Zorn, 2004), and the diffusion of such corporate governance practices as the golden parachute and poison pill (Davis & Greve, 1997), to name only a handful of topics.
Not surprisingly, the adoption and spread of university technology licensing has also been scrutinized from an institutional point of view (Nelson & Sampat, 2001; Owen-Smith, 2005; Berman, 2006; Vallas & Kleinman, 2008).

We have argued that academic entrepreneurship and technology transfer have evolved through three phases: an early era when it was uncommon and highly idiosyncratic (1960s–1980); a middle period when technology transfer expanded as a consequence of the Bayh-Dole legislation in 1980 and received considerable federal and state political support (1981–1993); and a recent era when the formal practices became ubiquitous and widely embraced (Colyvas & Powell, 2006; Colyvas, 2007b). While key legislative changes such as the Bayh-Dole Act in 1980 are common explanations for these phases, what makes these eras distinctive are the underlying processes that advance and reinforce the adoption of technology transfer practices. We have shown how the career ranks and patterns of collaboration shift in each of these eras as well as the composition of teams. The divergent concerns and foci of the eras are reflected in discourse as well, as we have illustrated in analyses of policy documents and correspondence at Stanford. Debates no longer occur over whether entrepreneurial science is appropriate for a university or how it should be fostered, but over its efficacy and degree of impact.

These different phases are also reflected in waves of foundings of technology licensing offices on university campuses. Prior to 1980, such offices were limited to less than 20 schools. These early entrants were an unusual mix, including state universities, such as Wisconsin, Utah, Minnesota, and Iowa State, along with private universities such as Johns Hopkins, MIT, and Stanford. Following the passage of the Bayh-Dole Act, which authorized and mandated the transfer of intellectual property rights to inventions generated by federally funded research; a host of new universities opened technology transfer programs between 1983 and 1995. Nearly every major U.S. research university set up an office by the mid-1990s, and over the next 10 years, smaller schools, medical centers, and research institutions joined the pack. Expansion also occurred in Canada, Europe, and Asia, albeit with about a 10-year lag behind the United States (Mowery & Sampat, 2005). Those that arrived on the scene more recently have found it necessary to justify themselves according to the standards of the early entrants, and accept metrics that are not necessarily well connected to their local circumstances.

Despite their proliferation, most TTO’s are small (one-third are staffed with three or fewer people), and even the oldest and most successful offices have only 12–15 full-time staff (AUTM, 2007). These staff must
engages with faculty inventors, patent attorneys, the USPTO, and a wide array of prospective licensees in the United States and abroad. Given the small number of personnel devoted to working with faculty and companies, it is not at all surprising that on most campuses, only a fairly small number of faculty are inventors.\textsuperscript{4} In addition, the majority of disclosures do not result in a successful license.\textsuperscript{5} Moreover, even among inventions that produce royalties, a tiny number are highly successful. For example, at Stanford in 2006–2007, there were 494 royalty-producing inventions, a very auspicious number compared to most universities. But only three of these inventions generated one million dollars or more in income (Stanford OTL Annual Report, 2006–2007).

At a broad level, the diffusion of TTO's and the incorporation of commercializing academic science into the mission of research universities suggest that these activities have become legitimate and highly institutionalized. Indeed, back in the 1960s and 1970s, technology transfer once referred to the movement of ideas from Western nations to the developing world; now the phrase evokes academy–industry interaction. But from a more fine-grained view, academic entrepreneurship is accepted but not widely practiced. And success at technology transfer is precariously dependent upon a few rare “blockbusters” (Owen-Smith & Powell, 2003). To make sense of these contrasting portraits, we need a richer understanding of how an activity can become embraced by many, but engaged in by few.

\section*{INSTITUTIONALIZING ACADEMIC ENTREPRENEURSHIP}

In many respects, an attempt to document entrepreneurship and gauge its durability in academic settings is a project about measuring institutionalization. By institutionalization, we mean the extent to which a practice becomes "built into the social order" and reproduced within organizations and the wider environment (Zucker, 1977). Once realized, an institutionalized practice becomes self-reinforcing in such a way that departures are counteracted and conformity is supported through “repetitively activated, socially constructed controls – that is, by some set of rewards and sanctions” (Jepperson, 1991, p. 145). Analysts often look to incentives as one mode of support, and sanctions as a critical reinforcement. We emphasize, however, that a focus on how to induce entrepreneurship often fails to capture the features that caused enterprising activity to take hold in particular settings, nor does it provide a
recipe for success elsewhere (Mowery & Sampat, 2005; Powell et al., 2007). For example, in an analysis of the introduction of commercial practices to Stanford University life scientists, Colyvas (2007a) demonstrates that the rewards and sanctions that are often touted by others as the basis for its local success emerged through considerable conflict with the existing norms of the academy, and, in turn, altered the context under which science was pursued. Consequently, we stress that incentives coevolve with local professional norms and circumstances, and are highly contingent on the degree of legitimacy of a practice for both individuals and organizations.

The spread of a practice may suggest that it has become widely accepted, yet many activities that diffuse never develop the foundations that enable them to persist. Increasing incidence and spread to more scientists are indeed suggestive of institutionalization. We explore additional indicators that highlight the degree of integration of entrepreneurship into the research and training aspects of academic science. Career stage and demography are important aspects to trace as prior research has demonstrated how academic entrepreneurship has spread from the periphery to the core—initially taking place off the tenure track through technicians and adjunct scientists, then jumping to high-status faculty, and eventually spreading down the career ladder to junior scientists (Stuart & Ding, 2006; Colyvas & Powell, 2007). Earlier career participation reflects a growing legitimacy of entrepreneurial science. Rather than requiring one to “earn her spurs” in science first, the extension of commercial science to junior career stages suggests acceptance during key stages of professional development.

An important determinant of institutionalization is the extent to which a practice becomes self-reinforcing. Scientific breakthroughs, federal legislation, and changes in IP policy all served to support a burgeoning trend in academic patenting (Mowery et al., 2004). What is authorized in the field and seen as desirable for organizations, however, is not necessarily accepted by individuals. At Stanford, many faculty in commercially relevant fields resisted the business aspects of technology transfer, encountered considerable ambiguity around inventorship, and developed disparate rationales to manage the conflicting boundaries between commerce and science (Colyvas, 2007a). Such confusion and contestation suggest that despite the external view that entrepreneurship was eagerly embraced or wisely rewarded, there was uncertainty among researchers about whether commercial science was appropriate.

We suggest that institutionalization can be distinguished by different degrees and accompanying processes. In the case of academic entrepreneurship and technology transfer, the phenomenon can occur through individuals,
such as faculty, staff, and students or technical personnel, or via organizational units, such as TTO's, entrepreneurship programs, or academic departments. Obviously, the two interact, as successful heads of TTO's can consult with or move to other universities, graduates of entrepreneurial laboratories can move to other schools and become enterprising faculty, and experienced department heads can be hired to bring vigor to settings that have been uninvolved in commercial science.

In one form of institutionalization, albeit a “thin” one, successful organizations that were early developers of a practice or structure become landmarks. Others who seek to emulate them convert their early success and recognition into aspirations. A template of purported key elements is lifted and transposed, often without the underlying processes or structures that reinforce them. A common example of this process is mimicry. Both individuals and organizations routinely copy those around them who are perceived to be more prestigious, successful, and worthy. Such efforts at repeating the successes of others can be challenging, however. Replication, especially without direct, sustained contact with the original source, can often be incomplete or a poor copy of the original. In such cases, institutionalization is largely ceremonial, or takes on faddish qualities. The early proliferation of technology transfer and entrepreneurial science was mostly symbolic and largely driven by emulation and replication, triggering a new regime of status-based competition in which universities showed the symbols, if not the fruits, of commercial efforts (Powell & Owen-Smith, 1998).

A deeper form of institutionalization involves reproduction through direct contact with, or exposure to, the initial source of an idea or innovation. Such contact permits socialization into the practices and mores, and enriches subsequent efforts to build on the original source materials. Drawing on these elements and recombining with local conditions in new settings both cultivates the original ideas and causes them to spread.

The strongest form of institutionalization is generative, affording the opportunity for a practice or structure to travel to new settings and venues. This migration is not a form of external emulation or synthetic replication. Rather consider regeneration as a means for an idea to become more varied and richer. Contemporary research on stem cells provides an apt metaphor, where a pluripotent cell can be transferred to a new environment and the interaction of “seed and soil” prompts maturation and differentiation. Ideas and practices build on the original model but integrate them into the context of indigenous circumstances, drawing on the original for sustenance but recasting it into local language and identities. This form of positive feedback can become self-reinforcing, allowing a practice to take hold as well as
Table 1. Forms of Institutionalization.

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<thead>
<tr>
<th>Characteristic Features</th>
<th>Thin</th>
<th>Reproduction</th>
<th>Deep</th>
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<td>Synthetic replication</td>
<td>Copy</td>
<td>Direct exposure to success</td>
<td>Maturation and differentiation</td>
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<td>Socialization</td>
<td>Recasting</td>
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<td>Borrow from established successes</td>
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<tr>
<td>Ramifications</td>
<td>Myths are revered and rationalized as they are copied</td>
<td>Deepens or grows as the practice spreads</td>
<td>More &quot;generative,&quot; varied and richer</td>
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<td></td>
<td>Little impact on developing new metrics</td>
<td>Taken-for-granted categories are accepted, but demythologized as new participants use them</td>
<td>Practices migrate and recombine with local circumstances</td>
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reproduce, seemingly without conscious intervention. Table 1 summarizes the three stages, the mechanisms that support each, and the ramifications of each form of institutionalization.

**DATA AND METHODS**

We draw on multiple sources of archival and publicly available information to inform our analysis, including disclosures, patent applications, and employment records of faculty and students at Stanford University from 1970 to 2000. We have also interviewed many of the faculty who were initially involved in commercial efforts, and the staff at the Stanford Office of Technology Licensing (OTL). Through a combination of descriptive statistics and network visualizations, we examine how involvement in commercial science developed, spread, and became self-reinforcing. We begin with an overview of the research setting, followed by a discussion of data sources and methods.

**Setting**

Stanford University has a long history of research and training achievement, rendering it as an apt setting to analyze the institutionalization of academic.
entrepreneurship and its consequences. The university was among the first to develop a formal technology transfer program in 1970, which started as a pilot program in 1968. Our sample is drawn from a life science department, known for its high-status research faculty and exceptional scientific achievement. The department was selected for its basic science focus, active doctoral program, and contribution of the first life science invention to the OTL. This unit had scant early contact with industry, and an orientation toward government-funded research. Thus it is a site where one would not necessarily expect entrepreneurship to take root. The department was founded by a Nobel Laureate in the 1950s. Initially, most early appointments were at the senior level. Relative to other nonclinical departments at the Stanford Medical School, this unit was small in faculty full-time employees (FTEs), yet was the largest in sponsored research expenditures. Most departmental research support came from the National Science Foundation (NSF) and the Department of Health, Education, and Welfare (DHEW). By the 1990s, the department expanded considerably and made numerous appointments at the junior level.

Sources

We collected data on faculty and student careers and inventive activity over a 31-year period, 1970–2000. These data afford us the opportunity to observe the institutionalization of academic entrepreneurship in its earliest stages when it was new to the field of research universities, new to Stanford, and new to individual laboratories. We draw on three sources of publicly available and archival data. Specifically, we collected the following.

Faculty and Student Records
We utilize university bulletins to obtain the names of all faculty and their rank by year for the basic life science department. Graduates of the department were identified through the Stanford University Library dissertation database on Socrates, which catalogues all Stanford dissertations by department, including title and year of submission.

Invention Disclosures
Invention disclosures reflect a formal submission to the university of a scientific finding for the purpose of commercializing it. We utilized the university Office of Technology Licensing archives to obtain information on invention disclosures, permitting us a sample of all inventions
emanating from this department through faculty, students, or staff. For collaborators not affiliated directly with the department, either as a student or faculty member, we identified their rank and employment setting at the time of each invention disclosure. University bulletins and Stanford’s dissertation database helped with the identification of individuals who were either graduate students or faculty at the time of disclosure. Proquest provided an additional source of identification, and a combination of Google, Pubmed, and Google Scholar helped us track down individuals who were research or technical staff or employed elsewhere.

Disclosures represent the initial step in the technology transfer process. In most instances, federal funding agencies require disclosure of any patentable invention, and faculty and students at Stanford were also encouraged to submit inventions to the OTL. In 1994, Stanford changed its policy to stipulate that the disclosure of any inventions that utilized university resources were a condition of employment. Still, compliance is not monitored closely and the TTO is aware that some inventions go out the “back door.” Rather than viewing such activity as “illicit,” the OTL sees such cases as an opportunity to provide further service (Interview with Kathy Ku, July 2007). Invention disclosures are a particularly useful data source as they provide a baseline with respect to inventive efforts. Not all disclosures are patentable or pursued by the OTL. The Stanford OTL has estimated that a small subset of submitted inventions (roughly 1/3) are patented and among that group, nearly half are licensed successfully. Disclosures provide a rich information source on student exposure to entrepreneurial activity prior to graduation. Research that focuses only on patents is, in one sense, sampling on successes, as well as the organizational capabilities of a university’s licensing office. Attention to disclosures provides a much fuller picture of the range of inventive efforts underway at a university.

**Patents**

To analyze patenting activity by faculty and students, we drew on the United States Patent and Trademark Office and National Bureau for Economic Research patent databases. We used a name-matching algorithm developed by Deborah Strumsky, working with Lee Fleming at the Harvard Business School. After initial name matching, we reviewed the lists for accuracy, in particular for cases of common names that are actually different individuals. Due to the considerable variation between the time of submission and granting of patents, we follow standard practice and rely on
application date for a uniform account of entrepreneurial activity across time and individuals. We reviewed each patent application manually, removing names where there were discrepancies in terms of time period, patent classification, and location. We identified 182 patent applications by 27 individuals between 1970 and 2004.

The use of patents as intellectual property protection varies considerably across academic fields and commercial industries (Cohen, Nelson, & Walsh, 2002; Rhoten & Powell, 2007). Patents are much more commonly used in the biopharmaceutical industry, and less typically relied on in high-velocity sectors such as telecommunications and software. Recognizing these differences is critical to understanding how academic entrepreneurial activity develops on university campuses and why it has been dominated by the biomedical sciences. For our purposes, however, patenting provides a means of identifying patterns in the privatization of public science and the location where such activity takes place through assignment. Taken together with disclosure data and archival records, patents provide a window into entrepreneurial practices and career transitions over a period of transformation.

Methods

To address our questions, we utilize network visualizations, descriptive statistics, and comparative data on student careers. In previous work we identified the ways in which the co-invention networks reflect the growing legitimation of academic entrepreneurship through changes in the composition of teams and clusters over time (Colyvas, 2007b; Colyvas & Powell, 2007). In this analysis, we focus more directly on students to analyze the relationship between entrepreneurial activity and careers. Recall that our aim is to develop indicators that more meaningfully reflect the extent to which academic entrepreneurship has taken hold within laboratories, departments, and the university. Rather than only counting outputs by a technology licensing office, we look to more processual measures that represent work at the laboratory bench. Focusing on faculty and student collaborations while at the university, and students’ postgraduate careers, sheds light on whether entrepreneurship is learned while in graduate school, or realized through postgraduate career choices. In addition, we can gauge whether graduate experiences were formative by looking at the patenting activity of students in their subsequent careers. For example, are students who had exposure to disclosing inventions while in the university
transformed by such efforts, as reflected in either their career choices or in patenting activity after leaving the university?

**Network Visualizations**
We begin our analysis with the entire department and address the distribution of inventive activity through network graphics portraying invention disclosures. This approach affords us the ability to analyze both demographic and temporal patterns of disclosure, and address the rate and direction of their spread. In the graphics, individual inventors are nodes, and ties between them reflect collaboration on an invention. The networks are analyzed in terms of components, or clusters of activity, comprised of individuals that are connected at least once, as a window into laboratories and their linkages. The networks are arrayed by size, career stage of individuals, and founding year of each cluster. We attend to three features in particular: the distribution of co-inventing, the composition of teams for individual inventions, and the composition of clusters of co-inventors.

**Careers and Students**
Invention disclosures and patenting provide indicators of graduate student exposure to commercial science during the research and training process. We look at students as they pursue their degrees and then follow them after they leave the university. We ask, first, whether students invent or not prior to graduation, and second, whether they engage in this activity after leaving the university. For entrepreneurial engagement while in school, student participation is analyzed in either networks of co-inventors, or in rare cases, solo invention. When students patenting after graduation are observed, we identify the assignment of the invention, whether the patent belongs to Stanford, another public research organization, or a company.

**RESULTS**
In earlier work, we analyzed characteristics of the department and the evolution of entrepreneurial activity, demonstrating the growing acceptance of academic patenting and deeper engagement with commercializing science (Colyvas & Powell, 2006, 2007). By most metrics, academic entrepreneurship increased markedly between 1970 and 2000 and spread deeper into department life. The number of faculty participating in disclosures increased from 1 faculty member out of 4 in 1970 to 18 out of 26 by 2000.⁹ In contrast, the percentage of students participating in disclosure activity is more
modest. Thus, while commercial engagement spread among faculty, supplanting activity by technicians and scientific staff, it did not "trickle down" to PhD students in a pronounced manner. The percentage of engaged PhD students remained relatively constant. The picture is much more complex, however, when we look at teams of inventors and changes over time in their composition, a point we develop below.

**Stages of Activity**

From a longitudinal perspective, the spread of disclosure activity advanced in stages, marked both by patterns in the frequency of participation and key regulatory events. Fig. IA provides an overview of the annual number of

![Graph](image-url)

inventors and their inventions. The number of disclosures is small from the early to middle 1970s and then jumps in the latter part of the decade and early 1980s, followed by a leveling off until 1993 when the number grows dramatically. Viewed cumulatively, there is a steady rise, followed by a plateau through the 1980s and an expansion in the early 1990s (Fig. 1B). The pattern is particularly interesting to consider in light of the passage of the Bayh-Dole Act in 1980 and a change in internal Stanford policy in 1994 that made disclosure mandatory. The interesting feature is that disclosure efforts declined following the Bayh-Dole Act, a period that marks the national authorization of technology transfers, as well as Supreme Court authorization to patent life forms. Moreover, several lucrative licenses both within the department and from other parts of the university were developed in the 1980s, but these did not attract many new participants. In part, this
"fallow" period reflects local debates about whether faculty should be permitted to have leadership positions in companies or take equity in return for their scientific contributions (Colyvas, 2007b).

**Department and Laboratory Context**

While the number of inventors increased over time, the expansion did not occur across the board, but rather within the context of entrepreneurial efforts in a few specific laboratories. Prior to 1981, disclosing was the province of but a few faculty members, as only three of the nine faculty that held appointments over that period were involved. Two prominent faculty research programs accounted for the majority of invention disclosures. Interestingly, the archival data reveal that other faculty were involved in research that culminated in a disclosure, but they did not list themselves as inventors on the submission. For example, the chair of the department was a co-PI with an adjunct faculty member who submitted repeated inventions. Another professor, who eventually had the most lucrative invention during this period, initially reasoned that inventorship was the purview of his technicians and staff who worked on the prototype. While he was the lead author on publications, he did not consider himself an inventor. It was not until the 1980s that this senior professor would list himself as an inventor. By the mid-1970s, faculty disclosures became more common but the activity remained highly limited and concentrated in a few very productive laboratories.

Between 1981 and 1993 disclosure activity increased, with 9 of the 19 faculties who held appointments during this era disclosing at least once. The size and demography of the department expanded, particularly in the latter years. Between 1989 and 1993, 11 new faculties joined the department, 2 of whom were experienced inventors. The department remained comprised of primarily senior faculty, with but only two of the new hires at the assistant professor level, for a total of only three junior faculty.

The period between 1993 and 2000 is marked by both widespread disclosing of inventions by veteran faculty and the engagement of new department members. All of the faculty in the department who were appointed prior to 1993 disclosed at least one invention by 2000. Among the 12 new hires made between 1993 and 2000, 4 submitted disclosures by 2000. The hiring of new members to the department with experience with patenting and the biotechnology industry, as well as the widespread
participation of existing faculty, suggests that entrepreneurship had become an accepted activity.\textsuperscript{10}

Given our interest in metrics and measurement, it is important to note the limitations of disclosure data in understanding entrepreneurial effort. The archives are replete with evidence of enterprising efforts emanating from this department prior to 1980, though such activity is not necessarily manifested in such measures as disclosures, patents, or industry funding. For example, the chair of the department through 1978 had considerable consulting experience with industry and was very active in bringing computing technology to the biological sciences. He was also integral to supporting the earliest faculty invention from this department, and championed the appointment of an already successful inventor as his successor as chair. The first two departmental chairs developed external ventures to advance new technologies, one with the computer science department in the 1960s that bridged artificial intelligence with biomedicine, and the other to distribute and support a biomedical software product.

\textit{Demography and Networks of Co-Invention}

The distribution of inventors over time provides insight into the patterns of disclosure and its emanation from particular laboratories. Fig. 2 provides a visual representation of inventors from 1970 to 2000, with their co-invention activity. This image includes all inventors in the sample, marked by career stage and affiliation. The shapes or "nodes" in the image represent individual scientists, and the lines between them reflect ties through joint invention disclosures. The individuals are coded by shape for career stage and by color for affiliation. Diamonds are faculty, ellipses are students or postdoctoral fellows, and boxes reflect other employees such as staff researchers and technicians. Members of the department are coded black, while inventors from other university departments are gray, and inventors from other universities or companies are white.\textsuperscript{11}

The networks are arrayed by cluster size on the vertical axis and chronology on the horizontal axis, based on the year in which the first invention appeared for each cluster. For example, in the upper left-hand quadrant of the image, there are two large clusters of inventors with founding dates of 1970 and 1978, respectively. While these figures include inventions over all years, the placement of the component on the far left of the figure reflects the year of the first disclosure by that group. Moving right along the image, there are two more large clusters that emerge in 1991 and
1994, along with several smaller components of 10 or fewer individuals arrayed below. At the very bottom of the figure, there are smaller clusters, consisting of inventor teams of three or less, spanning all the years. The vertical placement of the components by size has been adjusted to portray the largest components in the upper half of the image and the smaller groups or solo inventors in the lower half.

Visualizing the distribution of inventive activity in terms of clusters (or teams with at least one degree of separation), and chronologically by the founding year for each cluster, adds texture to the stages observed in Fig. 1(A) and (B). Viewed relationally, the decline in disclosure activity observed in the 1980s underscores several key points. First, all of the large clusters in the image are concentrated in either the 1970s or the 1990s. The limited activity in the 1980s occurred either in existing inventive research programs founded in the 1970s, or in small teams of two or three inventors that are one-time collaborations or solo disclosures. Existing research programs provided the foundation for subsequent new disclosures, as very few new teams of inventors formed during the 1980s. In contrast, numerous new clusters of co-inventors emerged in the 1990s and continued to collaborate and invent throughout the decade. The invention teams of
the 1990s also involved numerous linkages to collaborators outside the department and university.

Second, the configuration of the clusters, centered on a senior faculty scientist, is telling. Research programs are organized around a faculty PI and his or her laboratory. Postdocs and students train in these laboratories, often funded on grants and contracts. Their joint work typically results in publications. The convention of authorship reflects this structure, with the first author usually the lead scientist who performed the experiments, followed by other contributors, and ending with the senior scientist who is the PI of the laboratory as the last author. The shape of the disclosure networks depict faculty who hold central positions in these components.

Third, these factors shape the manner in which academic entrepreneurship spread into early-career stages as observed in the distribution of the activity. The increasing involvement of more faculty pulled in earlier career stage scientists – resulting in more junior scientists involved first as collaborators with senior scientists, and then more teams of junior scientists inventing on their own. Finally, consider the dynamics observed in the empirical data. The repeat participation of early clusters, which drew in new collaborators, sustained the activity in the middle period. At Stanford, the growth in invention disclosures in the 1980s came from more repeat activity by “veteran” research programs. At one of the leading departments in a university that is widely regarded as entrepreneurial, federal and legal changes in the 1980s had limited effect. The socialization process within the department and the incorporation of commercial science into the purview of scientific identity proved more consequential than policy mandates.

Together, these data suggest a shift in the acceptance of academic entrepreneurship as commercializing science became “everyday” practice in laboratories. Table 2 summarizes inventorship by rank for each individual

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<tbody>
<tr>
<td>Faculty</td>
<td>31%</td>
<td>44%</td>
<td>48%</td>
<td>45%</td>
</tr>
<tr>
<td>Postdocs or fellows</td>
<td>13%</td>
<td>12%</td>
<td>10%</td>
<td>11%</td>
</tr>
<tr>
<td>Students</td>
<td>6%</td>
<td>15%</td>
<td>20%</td>
<td>17%</td>
</tr>
<tr>
<td>Scientific or technical personnel</td>
<td>46%</td>
<td>19%</td>
<td>11%</td>
<td>18%</td>
</tr>
<tr>
<td>Scientists at other universities</td>
<td>4%</td>
<td>8%</td>
<td>9%</td>
<td>8%</td>
</tr>
<tr>
<td>Scientists at companies</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Number of individuals cases of disclosing</td>
<td>54</td>
<td>137</td>
<td>283</td>
<td>474</td>
</tr>
</tbody>
</table>

incident of disclosure. Note the dramatic change in share of inventing by period. Between 1970 and 1980 there are 54 incidents of disclosing, 137 between 1981 and 1993, and 283 during the seven-year period of 1994–2000. The data include repeat activity by the same inventor and all the inventors listed on each invention. Note the increase in the pace of inventing, with an average of 40 incidents of individuals disclosing in period three, compared to 11 on average in period two. There is also a notable shift in the profile of inventors. Prior to 1981, scientific or technical staff account for 46% of inventing activity. Faculty makeup only 31 percent. Between 1981 and 1993 the profile changes, with only 19% of inventive activity done by technicians while faculty participation increased to 44%. The records demonstrate that as commercializing science spread it permeated further into academic, tenure-track ranks, and earlier career stages as well. Note also the change in percentage of students, only accounting for 6% of the inventive activity prior to 1981, then 15% between 1981 and 1993, and finally 17% between 1994 and 2000.

While the total percentage of students participating in invention disclosures may appear small, when viewed relationally and as a percentage of overall inventive activity, the trend is more consequential. Comparing the amount of activity using simple count metrics reveals limited difference in the periods. But we suggest the meaning of disclosing and patenting changed markedly, as younger scientists increasingly participated in disclosure activity and began to disclose on their own, without the assistance of senior colleagues. So while conventional metrics suggest little change, they mask an important shift as younger scientists became independent entrepreneurs.

*Patenting and Employment Patterns among Doctoral Graduates*

Scant research has looked at doctoral student involvement in inventive efforts (see Chapter 5 by Stephan for a notable exception). We suggest that participation by students and junior faculty is a key indicator whether academic entrepreneurship has taken hold and become commonplace. For better or worse, participation by lower and entry ranks suggests a practice has gained “legs.” Rather than the older model of first acquiring scientific fame in the world of the academy and then “cashing in” later, this new stage of participation signals that science and commerce are seen as complementary and mutually reinforcing (Owen-Smith & Powell, 2001; Colyvas & Powell, 2006). To further pursue these ideas, we turn to an analysis of PhD
students who graduated from this department over this 31-year period. We address the effects of experience and exposure over the three periods.

Table 3 summarizes patenting and employment patterns for the 21 doctoral students that graduated between 1970 and 1980. The table provides information on both invention disclosures and patents before and after graduation, followed by a breakdown of whether post-PhD patents were assigned to universities, industry, or individuals. Table 3 also includes the employment outcomes of these graduates by university (including public research organizations) and industry in cases where this information was available.

Overall, patenting was uncommon for students during this early period, with no one applying for a patent before graduation and only 6 individuals filing 23 applications after graduation. There is slightly more disclosure activity, with 1 student included on a disclosure and 4 who filed 11 disclosures postgraduation. We assume these postgraduation disclosures involve either students who went on to do postdocs at Stanford or reflect work that continued after graduation. Commercial activity is relatively rare among this cohort of graduates, especially considering that they have had 25–35 years to patent since graduation. Of the patenting that takes place, it appears more fertile inside universities, with 3 academics producing 19 patent applications, compared to only 4 patent applications produced by the same number of industry scientists. Employment information was difficult to obtain as it required going back in many cases more than 25 years. Consequently, we were unable to find current positions for 11 graduates, and could not find first jobs for 9. From the available

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Prior to PhD</th>
<th>Post-PhD</th>
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<tbody>
<tr>
<td>Disclosures</td>
<td>4 (4)</td>
<td>2 (28)</td>
</tr>
<tr>
<td>Patent applications</td>
<td>2 (2)</td>
<td>15 (62)</td>
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<thead>
<tr>
<th>Patent assignment post-PhD</th>
<th>University</th>
<th>Industry</th>
<th>Solo</th>
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<tbody>
<tr>
<td>5 (11)</td>
<td>9 (48)</td>
<td>2 (3)</td>
<td></td>
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</table>

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<thead>
<tr>
<th>Employment or Postdoc Position Post-PhD</th>
<th>University</th>
<th>Industry</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>First job</td>
<td>22</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Current job</td>
<td>13</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

Note: N = 33.

Information, 12 graduates had a first job in a university and none were identified in industry. In terms of current employment, seven are in universities and three are now in industry. One is with a large pharmaceutical company, and two are with biotech companies. This first era of students stayed close to the academy and traditional scientific norms, with limited involvement in patenting in their postgraduate careers. When patenting did occur, it took place in a university setting.

Table 4 shows the patenting and employment patterns for the cohort graduating from 1981 through 1993. Patenting (i.e., patent applications) and disclosing while a student increased slightly after 1980, with 2 of the 33 graduates applying for a patent, and 4 listed as inventors on the same number of disclosures. After graduation, however, the number and quantity of patent applications increased dramatically, with 15 individuals producing 62 patent applications by 2004. Furthermore, these patents are now largely assigned to industry, with 48 listed with companies, compared to 11 to universities and 3 to individuals. The disclosure data post-PhD is suggestive as well. While only two individuals submit disclosures to Stanford after graduating, these 2 are highly engaged, producing 28 inventions. Employment immediately post-PhD remains largely at universities, with 22 of the 33 graduates confirmed as taking a postdoc or research position in a university and only 4 going into industry. These data are not surprising considering that postdoctoral training is a typical career step in the basic life sciences. Yet many more graduates ended up in industry than in the previous era, as current jobs are split between 13 in the academy and 12 in industry. Clearly, both patenting and industry jobs have become more

<table>
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<th>Productivity</th>
<th>Prior to PhD</th>
<th>Post-PhD</th>
</tr>
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<tbody>
<tr>
<td>Disclosures</td>
<td>6 (6)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Patent applications</td>
<td>1 (1)</td>
<td>6 (93)</td>
</tr>
<tr>
<td></td>
<td>University</td>
<td>Industry</td>
</tr>
<tr>
<td>Patent assignment post-PhD</td>
<td>3 (8)</td>
<td>3 (85)</td>
</tr>
<tr>
<td>Employment or Postdoc Position Post-PhD</td>
<td>University</td>
<td>Industry</td>
</tr>
<tr>
<td>First job</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Current job</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: N = 30.

common. Among the graduates that went into industry, the majority has gone to biotechnology companies, rather than large corporations. We find eight in biotech and four in biomedical or pharmaceutical companies. Patent assignment evinces a similar pattern, with 31 patents assigned to small biotech companies and 11 to large biomedical firms. While we are unable to access data on disclosures by graduates who moved on to other universities, the patenting records show a notable shift. For this cohort, patenting is fairly commonplace after, but not before, graduation and it occurs primarily at companies not universities.

The most recent cohort of 30 students, summarized in Table 5, evinces another change in both pattern and context. At first glance, the difference in patenting and disclosure patterns does not seem to depart markedly from the second era. Six students appear on six invention disclosures, and only one student is listed as an inventor on a patent prior to graduation. But remember that this period covers only seven years. The average number of graduates increased during this era, with 4.2 doctorates completed per year compared to 2.5 between 1981 and 1993 and 2.1 between 1970 and 1980. The number of graduates coincided with increases in the number of faculty in the department. The striking difference is the number of patents produced after graduation, especially given the recency of this cohort. Despite their relative youth, six individuals from the sample generated 93 patent applications during this most recent period. The move to patent in industry versus the academy is split equally among individuals, but with 85 of the 93 patents assigned to one company. Most graduates take postdocs in academic settings, as only 4 moved directly into the biotech industry while 21 started
their careers in universities. Patenting takes place both in biotech companies, accounting for 49 of the assignments to 4 companies, as well as 3 pharmaceutical companies with 36 patents. Clearly, this recent cohort is more engaged in patenting, whether they are working in the academy or industry. In one respect, the differences between the second and third cohorts of graduates may not appear significant because overall disclosure and patenting activity are similar. But keep in mind that one cohort covers 13 years, the other only seven. Also, note the increase in magnitude. Those who patent in the third era do so more quickly and in greater number, reflecting increased engagement with industry, even from an academic setting. This enhanced contact reflects a settling of the boundaries and modes of exchange between university and industry. Changes in the field of biotechnology and relations with universities opened up more opportunities for start-up company formation without having to leave the university, as well as attractive postdoc positions and research opportunities at companies. Moreover, the integration of science and commerce reflects the extent to which academic achievement and commercial acumen have become intertwined.

CONCLUSION AND IMPLICATIONS

From a public policy standpoint, the broader question of whether academic entrepreneurship has been beneficial to universities and science has been displaced by the development of metrics and benchmarks to gauge its success. In our view, many of these efforts to bring entrepreneurial practices into university science hinge on metrics that are poorly suited for local circumstances and overlook relevant indicators that entrepreneurial practices have become sustainable in a university setting. More attention to measures that reflect the strengths as well as constraints of particular universities would enrich the portfolio of standards by which entrepreneurial efforts are assessed. A greater focus on the activities of scientists, in particular graduate student involvement in commercial work both pre- and post-graduation, would afford a richer discussion of both the degree of institutionalization of entrepreneurship as well as its social and economic consequences.

We addressed the ways by which technology transfer at Stanford University spread, reproduced itself, and became self-reinforcing. We showed that even in a notable department at a university known for its success at technology transfer, the growth of disclosing was uneven and reflected very different kinds of participation. In the early period, the most
active disclosers were technicians, not faculty, as academic scientists did not consider themselves inventors. Then inventing became the province of a few distinguished scientists and others were introduced to the activity via them. Only more recently did younger faculty and PhD students invent on their own without senior sponsorship. While the level of involvement surely changed, those who participated and their form of involvement shifted even more dramatically.

We emphasize that reinforcement is an important feature of institutionalization. Merely charting the increase and spread of inventing does not capture the full extent to which entrepreneurship became embedded in academic laboratories and integrated into research and training. Recall Fig. 1, which showed the distribution of disclosure activity over the 31-year period, demonstrating a stage-like progression in the diffusion of academic entrepreneurship. In the initial years, disclosure activity was marked by the entry of a few high-status faculty, supplanting the earliest inventors who were mostly non-tenure-track scientists and technicians. The 1980–1993 era was characterized by disclosures emanating from a few prolific inventive programs. Thus, while entry typified the initial era, persistence sustained the period of 1980–1993. Finally, by the third era, the expansion of the number of inventive clusters reflected both the growth of the department and the increased likelihood of faculty inventing. The increase in the number of clusters and the rapidity with which they cohere provide potent indicators of reinforcement. While new scientific opportunities prompted entrepreneurial efforts by faculty, and the persistence of their research programs supported it, the expansion to more laboratories and earlier career stages provide two key metrics of how academic entrepreneurship gained traction.

A network perspective sheds light on the extension of academic entrepreneurship down the career ladder, indicating not only its increasing legitimacy in the academic setting but its reproduction as more students become exposed and socialized. Senior faculty enrolled early-career stage scientists through collaborations and the organization of their academic laboratories. Networks of scientific collaboration played a crucial role in institutionalizing commercial science. The emergence of teams of early-career stage scientists disclosing independently of senior faculty provides a robust indicator of institutionalization. Consider the difference between postdocs and students inventing in teams on their own rather than only alongside faculty sponsors. The independent, younger inventors formed the core of a new generation.

A key distinction can be drawn between reproduction and reinforcement. The former is reflected in more PhD students included on invention
disclosures with either their advisors or other senior faculty. Inventing, like publishing, has become a “team sport,” especially in the life sciences (Bercovitz & Feldman, 2008). In this context, the growing involvement of faculty pulled in PhD students and taught them the ropes. Moreover, the younger scientists saw that their mentors were now disclosing and that patenting was considered an acceptable, perhaps even necessary, part of a career. Reinforcement occurred in two parts. The composition of the clusters showed that younger scientists are taking initiative and no longer dependent upon the lead of high-status senior faculty. The second aspect of reinforcement comes through an examination of postgraduate careers of students. Whether experience in commercializing science as a graduate student has an imprinting effect is a means of gauging if commercial science has “gained legs.”

One explanation for the greater involvement of students is that the career structure of science was altered to incorporate private science into a university setting. As one reflection of this integration, graduates of the department often moved to small biotechnology companies where translational research is central. Many small firms are spin-offs or start-ups that draw readily on university science. Research has suggested that small life science firms are organized more like university laboratories and engage in basic research as they straddle academic and industrial domains, while large pharmaceutical firms represent a passage out of academic science into a more permanent career in industry (Smith-Doerr, 2004; Whittington, 2007). Thus, tracking the types of careers students pursue postgraduation is essential, as different forms of employment afford very distinctive opportunities, some of which permit graduates to retain a hand in the scientific enterprise. Indeed, in our data from the period II and III cohorts, we found much more patent assignment and career moves into smaller companies than large ones, particularly in the most recent era.

We argue that many commonly used commercialization metrics, such as number of patents, are limited in capturing how high-quality science is produced and transferred. Patenting data provide a window into how generative commercialization activities have become – that is, the extent to which the fruits of laboratory research are harvested elsewhere. Disclosures capture a wider range of inventive activity than is reflected in patenting, particularly in such areas such as biological materials where patenting is less common and graduate students are most likely to be involved. A comparison of these data sources and the socioeconomic context during these periods is suggestive. First, patents do not reflect the full spectrum of entrepreneurial activity taking place inside of universities, and second,
there may be some settings that are more conducive for follow-on disclosure than others. Finally, many disclosures reflect non-patented inventions that provide an important conduit to commercial activity inside the laboratory.

Few extant measures of technology transfer speak to the crucial question of training and developing future producers of socially and economically important knowledge. Analyses of student mobility patterns are important, keeping in mind the implications for the extent to which exposure to commercializing science may alter careers. In our sample, we had numerous individuals that went into industry science, venture capital, or managerial positions and never patented. On the other hand, some who went to industry continued to publish and patent. Immediately postgraduation, the majority of students in our sample went on to postdoctoral positions where they continued to contribute to the world of open science. Studies of academic entrepreneurship should attend to the multiple modes by which scientists participate in commercial activity, and distinguish among careers where there is scant involvement in publishing from those that allow for publishing and patenting.

A core question for universities is to assess whether technology transfer policies and modes of engagement are having adverse effects on research training and subsequent careers. What does it mean for graduate students to become deeply involved in commerce at key training points in their careers? Consider the implications for research and training if junior scientists’ exposure to important milestones such as peer-review and grant making are bypassed in a greater allocation of effort toward entrepreneurship. For universities, the question to ask is whether public and private science go hand in hand, whether there is a segregation between the two realms, or whether one has a dampening effect on the other.

Finally, as some metrics resonate for universities, other important indicators of scientific development and commercialization are lost. Commensuration, while making many organizations reactive, may also be mobilized. We have put forth a set of more localized metrics to capture how deeply reinforced commercializing science has become and identified potential ramifications that extend beyond conventional counts such as income generated or the number of start-ups, patents, and licenses. Addressing whether new clusters of inventive activity have formed, the composition of teams, and how engagement varies by career stage offers insight into the degree of institutionalization within universities. Rather than rely on high-profile successes, one might examine the activity of the new generation of scientists, and the form that academic entrepreneurship takes. For example, at universities that are relatively new to technology
transfer, rather than count the percentage of overall faculty that are involved in technology transfer, the percentage of recently hired faculty might provide more insight into how entrepreneurship is taking hold. Exposure to commercial science with teams of faculty or independently in entrepreneurial laboratories suggests socialization in the context of research and professional training. Career transitions and follow-on inventing lend insight into whether academic entrepreneurship reproduces itself in large companies or becomes more generative as new academic laboratories are established or research programs are continued in small biotechnology companies. Some universities may find important variations along these dimensions that are consequential to their missions or assumptions about their contribution to research and development.

NOTES

1. As a law school dean told Espeland and Sauder (2007, p. 11): “Rankings are always in the back of everybody’s head. With every issue that comes up, we have to ask how is this impacting our ranking?”

2. As but one example of the quandrum, a technology transfer officer at a large state medical center who moved into his job from a position in industry recounted the following story to us. He felt the office was filing too many patents, and not paying sufficient attention to developing relations with potential licensees. He reduced the number of patent applications, which were expensive to process and file, and increased the number of licenses by focusing on marketing and generating relationships. When the new data were reported, he promptly received a phone call from a university trustee asking why he had made the TTO “less innovative.”

3. For example, a handful of universities, including Stanford and Berkeley, have become involved in programs that focus on the social impact of technology transfer attempting to and facilitate access to important technologies for underdeveloped areas (Check, 2006). In 2006, Kathy Ku and Arthur Bienenstock at Stanford convened a meeting of research officers and licensing directors to discuss important issues affecting university technology transfer. The outcome of the meeting was a document of 9 points signed by 11 universities, in conjunction with the Association of American Medical Colleges, which urged universities to pursue open rather than exclusive licenses and to facilitate the transfer of knowledge for social purposes (McCarthy, 2007).

4. The issue of how inventive faculty “actually” are is a complex one, with many intriguing questions. Obviously, there is wide variance between the humanities and social sciences, on the one hand, and the physical, life, and engineering sciences, on the other, in the potential of the object of study to result in a commercial application. The knowledge flows between the academy and industry are quite diverse, and can be the result of consulting, trade secrets, sponsored research, personnel movement, and advisory board membership, to mention just
a few (Murray, 2002). Recent research documenting that a healthy number of patents developed by university faculty are assigned to companies or other public research organizations suggests that "spillovers" are much more extensive than many metrics imply (Audretsch, Aldridge, & Oettl, 2006; Thursby, Fuller, & Thursby, 2007).

5. While much has been made of charges of licensing officers engaging in "hold-up" or operating as "ponderous bureaucracies," the small staff size helps explain both charges. With limited resources, licensing staff may well feel that they have to hold out for the best deal, and they lack the resources or networks to shop inventions widely (Clinton, 2005; Kauffman, 2007).

6. At an individual level, scientists may have multiple reasons for seeking to emulate the success of their colleagues. They may perceive a colleague's success as a new standard of accomplishment, a novel means to fund research or replenish laboratory expenses, a just reward for a career of dedication to discovery, a means to attract promising graduate students, or a new status marker of wealth (Owen-Smith & Powell, 2001).

7. Now the National Institutes of Health.

8. These data are available back to 1975, and in some instances prior to this data, although the USPTO does not offer the capability to search for patents by inventor prior to this year. Based on our archival sources at the OTL, we did not identify any additional prior patenting activity in our sample among the life science faculty.

9. This number excludes two assistant professors who joined in 2000.

10. For a more detailed analysis of faculty disclosing in the context of their research programs and experience, see Colyvas and Powell (2007), where we demonstrate how faculty inventive activity transformed the demography of the department.

11. The network visualizations were created using Pajek version 1.09 and optimized three times using the Kamada Kawai optimization function. The components were extracted and manually arrayed in the figures to reflect the date of first invention for each node. The nodes and ties were coded with the year of disclosure, and the "generate in time" function in Pajek was utilized to visualize the networks at selected intervals.

12. The integral role of staff scientists and technicians during the early period, and its subsequent drop in later years is addressed in Colyvas (2007a). While many faculty questioned the legitimacy of patenting and licensing their academic research, these faculty supported nontenure track scientists and staff technicians in patenting scientific findings, either for their own benefit or to advance the laboratory's overall research program.

ACKNOWLEDGMENTS

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