FROM VULNERABLE TO VENERATED: THE INSTITUTIONALIZATION OF ACADEMIC ENTREPRENEURSHIP IN THE LIFE SCIENCES

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ABSTRACT

We examine the origins, acceptance, and spread of academic entrepreneurship in the biomedical field at Stanford, a university that championed efforts at translating basic science into commercial application. With multiple data sources from 1970 to 2000, we analyze how entrepreneurship became institutionalized, stressing the distinction between factors that promoted such activity and those that sustained it. We address individual attributes, work contexts, and research networks, discerning the multiple influences that supported the commercialization of basic research and contributed to a new academic identity. We demonstrate how entrepreneurship expands from an uncommon undertaking to a venerated practice.

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INTRODUCTION

Much contemporary discussion of entrepreneurship celebrates risk-taking individuals, who either by dint of their skill or charisma forge new paths, be these in the form of companies, social movements, or causes. Whether such activity requires the formation of a new organization or involves the reform of an existing one, these efforts are seen as valorous. This present-day veneration often ignores, however, the social context in which entrepreneurship initially occurs. Immigrant entrepreneurs are seen as creating jobs and wealth for their ethnic communities, but the strains and challenges to a stable social order are often downplayed (but see Portes & Sensenbrenner, 1993). Champions inside companies are viewed as virtuous reformers, but the settled ways of doing things provided comfort, routine, and solidarity to many. We seek to more closely analyze the settings out of which enterprising efforts emerge, and understand the risks involved for those pursuing new paths as well as the possible costs of a change to an existing order. We emphasize that entrepreneurship is rarely a single momentous act, but an incremental process and its reinforcement is very much a social accomplishment. The manner in which efforts at entrepreneurship are supported or contested is critical to its reproduction.

To explore these issues, we examine the origins, acceptance, and spread of academic entrepreneurship in the biomedical field at Stanford, a university that championed efforts at translating basic science into commercial application. We define academic entrepreneurship as the practice of disclosing inventions, filing for patents, or working with biomedical companies. With the use of multiple data sources spanning 1970–2000, we document a slow rise in these endeavors, with considerable discussion and uncertainty surrounding early enterprising efforts, then a contested period, followed by a growing acceptance, much increased activity, and eventual celebration. Our focus is on how entrepreneurial pursuits became institutionalized; hence, we examine the feedback processes that buttress such activity and contribute to a new academic identity. The data afford assessment of how commercially relevant science spreads through a key academic department. Over this period, academic entrepreneurship expands from an uncommon undertaking to become a venerated practice. We focus on individual characteristics, the work context, and the research networks within and across laboratories. Our aim is to examine which faculty are initially engaged in commercialization, which ones persist at such activity, who new entrants invent with, and how the composition of inventors changes over time.

We take a broad view of entrepreneurship, attending not only to the formation of business ventures, as is common in the literature, but also the creation of new organizational identities and practices (Hwang & Powell, 2005). We follow the classic formulation of Schumpeter (1934), who argued that entrepreneurship involved the recombination of existing resources and practices to introduce either novel products, methods of production, sources of supply, markets, or modes of organization (Swedberg, 2000; Fagerberg, 2003). We extend this approach to analyze how scientific identities that combined academic norms with industrial considerations emerged and spread. In our view, academic entrepreneurship was an integration of novel roles and resources into existing organizational contexts, triggering the creation of new models of what a researcher should be doing. This transformation was accompanied by an expansion of university administrative procedures to support these new activities (Colyvas & Powell, 2006). Eventually, academic entrepreneurship became both highly scripted and widely valued. Seen more abstractly, the argument we advance also provides insight into the emergence and development of entrepreneurial activity in other settings where such efforts were once viewed as unconventional.

Our starting point is a discussion of invention and entrepreneurial activity within the context of university-based science. Having chosen a university that has in place many of the elements that researchers identify as necessary to support academic entrepreneurship, we advance arguments that stress the feedback mechanisms that reinforce academic entrepreneurship. The research site, Stanford University, and our data are introduced next. Our analysis highlights the process by which entrepreneurial behavior spread within a basic biological science department, using data on inventors and their attributes, number of disclosures, research expenditures, and revenues. We utilize visualization tools to represent the relational networks that constituted invention disclosure teams. These methods allow us to capture the trajectory of growth of inventive activity. We examine the relationships between scientists and their discovery efforts, analyzing how the practices and meanings associated with entrepreneurship change over time.

ENTREPRENEURSHIP IN THE UNIVERSITY CONTEXT

For much of the last century, the practice of academic patenting was uncommon, especially in the life sciences (Mowery, Nelson, Sampat, & Ziedonis, 2004). The norms and reward system of science did not place a high value on faculty involvement in commercializing research findings. A 1968 letter to *Science* made the point that publishing was the primary objective of university researchers, and "many academic investigators ...overlook or ignore the invention and patentable results of their work." (Macy, 1968). The author was speaking from the point of view of the Research Corporation, the foundation that handled most university licensing prior to 1970. As one of the earliest technology licensing professionals, he underscored the importance of understanding academic science, and the objectives of university researchers: "If the objective of the research is new scientific knowledge, or the introduction of students to meaningful investigation, once this objective is reached, the sole remaining step taken by the investigator is to publish" (Macy, 1968).

Gradually, however, universities such as Stanford became more directly involved in marketing basic science discoveries. Such steps were not without controversy. A few high profile cases emerged that challenged both the desirability and appropriateness of commercial activity. "I do not want to sign a letter saying that I was just another laboratory worker," commented a University of Michigan professor to *Nature* in 1980 when the now famous recombinant DNA patents were under scrutiny (Dickson, 1980, p. 388). The patenting process, which required 'disclaimers' on the patenting application from co-authors and other scientists that they were not inventors, contravened scientific conventions of dissemination and credit. One of four authors on the original publication, this professor challenged the idea that his scientific input was marginal: "I was part and parcel of the whole thing; I don't feel that I should sign something that I do not believe is true" (Dickson, 1980, p. 388). The logic of the patent system conflicted with ideas about the cumulative aspects of scientific discovery, putting scientist-inventors under professional scrutiny.

Much ferment was underway in national policy debates in the late 1970s about the lack of university contribution to industrial competitiveness. In 1980, Federal legislation was passed encouraging universities to facilitate technology transfer. Most notably, the Bayh-Dole Act harmonized institutional patent agreements across federal funding agencies, allowing universities to take title to inventions developed as a result of government sponsored projects. The same year, a milestone Supreme Court ruling, Diamond versus Chakrabarty, allowed the patenting of human life forms, while one of the first biotech companies, Genentech, had a hugely successful initial public offering. These developments helped fuel an upsurge in patenting by U.S. universities during the 1980s, led by research in the life sciences (Mowery et al., 2004; Owen-Smith, 2003). But many technology

transfer offices (TTOs) were faced with the harsh reality that successful licenses were few and far between. Most TTOs struggled to break even, and profit was highly concentrated among a few universities.

Nevertheless, the revenues garnered by a handful of universities, including MIT, Stanford, and the University of California system, raised questions about missed opportunities at other schools. A 1989 *Economist* article drew attention to Indiana University's 1957 license to Procter & Gamble that gave rise to Crest. The royalty formula for "one of America's most popular toothpastes" was based on the amount of substance utilized, rather than sales of the final product. "Indiana got about $4 m when it might, by some estimates, have $100 m. Given today's slick marketing, such mistakes are unlikely to be repeated in many ivory towers" (*The Economist*, 1989, p. 82).

As the biotechnology and software industries burgeoned, the 1990s witnessed a continuing expansion of university technology transfer programs. At Stanford, a policy was passed in 1994 that any inventions done with university resources had to be submitted for university review. This policy further integrated academic entrepreneurship into the mission of the university. One indication of the growing acceptance of this goal was the scant protest over this broad claim to intellectual property. Entrepreneurship in the academy became regarded as central to economic growth. In 2002, the Bayh-Dole Act was hyped in *The Economist* as "innovation's golden goose," and as "[p]ossibly the most inspired piece of legislation to be enacted in America over the past half-century..." (Economist, 2002, p. 3). By the new century, university involvement in commercializing science was widely supported.

Research on entrepreneurship has largely fallen into two camps – an individual focus that emphasizes the motivations, experiences, and attributes of entrepreneurs, and a structural perspective that underscores the circumstances that afford opportunities or access to resources and environments rich in institutional support. In our interviews with prominent scientists who were active inventors and engaged with successful start-up firms, both themes were echoed. For example, one tenured molecular biologist, who was an early entrepreneur and founded a company, posed the question to us: "What motivates people to study a particular disease? Is it money or personal health?" He went on to note that he has had cancer twice, and had many friends die from AIDS. "Look at my research, it deals with HIV and cancer" (Owen-Smith & Powell, 2001a, p. 123). His comments illustrate how a scientist's personal experiences and relationships influence the direction of his science. Similarly, a senior neuro-immunologist observed that peer effects and monetary rewards had become very entangled: "I think this is an extraordinary place because so many people in your reference group are running around inventing things…" He went on to note that "it would be hard to ignore how fabulously wealthy some of your peers are. You notice the kinds of cars they park in the lot, and your children interact with their children…" (Powell, Owen-Smith, & Colyvas, 2007). These comments highlight how deeply intertwined social and economic motivations are.

A different rationale was offered by an eminent scientist who developed a prototype research device. "We needed a company to make the [technology] so other people could use it." He argued that this technology would transform the field by dramatically increasing the speed at which research was performed. The proceeds from making this research tool ubiquitous, however, were not intended to return as personal gain, but instead to feed back into his laboratory and replenish the funding for the research program that generated the discovery (Colyvas, 2006). Thus, both the desire to bring inventions into the world of practice and to generate resources for his laboratory fueled this scientist.

Researchers have identified other individual attributes and motivations that have drawn scientists into the world of commerce. Intellectual capital, measured by scientific productivity ("star scientists"), career stage (tenure), and experience (co-publishing with many authors) have been linked to both the proclivity to patent and involvement in start-up firms (Zucker, Darby, & Brewer, 1998; Thursby & Thursby, 2002; Stuart & Ding, 2006). In addition, a scientist's expertise, personal experience, and tacit knowledge of an invention may be so considerable that she needs to have a hand in any downstream development, thus leading to involvement in a start-up company (Shane, 2004; Lowe, 2006).

From a more structural perspective, researchers have examined why some disciplines and universities have been more conducive to faculty involvement in commercial activities, stressing the importance of university policies, culture, a supportive technology transfer office, and the presence of a medical center (Etzkowitz, 1998; Owen-Smith & Powell, 2001b, 2003; DiGregorio & Shane, 2003). Lach and Schankerman (2004) highlight the role of university-designed incentives that encourage faculty to reap gains from focusing on downstream applications of their research. Stephan et al. (2005) find that there are notable differences in patenting across academic fields, with biomedicine the most active area, followed by the engineering and physical sciences. They report that patenting activity is highly skewed, and significantly related to number of publications.[1]

Others who study academic entrepreneurship have attended to the wider environment in which universities are situated, noting that the growth of

such activity may be propelled by the desire of universities for more resources and autonomy (Slaughter & Leslie, 1997). More critical analysts contend that entrepreneurship reflects industry's growing embrace of, and influence over, university research (Krinsky, 2003; Washburn, 2005). A rich vein of work has looked at MIT, noting how its unique ecosystem has fostered discovery and linked academic inventors to entrepreneurial firms in multiple forms, ranging from the sharing of research tools to advisory board membership to visiting scientists to company founders (Agrawal & Henderson, 2002; Murray, 2002; Shane, 2004). More broadly, the process of "spawning," that is the role of either commercially engaged universities or large corporations in generating a talent pool of entrepreneurial scientists and managers, has been found to be critical to the founding of new firms (Gompers, Lerner, & Scharfstein, 2003; Higgins, 2004; Bercovitz & Feldman, 2005).

We do not downplay the role of university initiatives or individual motivations and attributes in fostering academic entrepreneurship, but we also explore alternative arguments concerning the structure of laboratory life and the research networks in which scientists are involved. We show that faculty engagement with industry varies over time, as different eras reflect divergent levels of acceptance. The context in which research is conducted helps define the range of appropriate opportunities that individual scientists may pursue. By looking at inventive behavior over a 31-year period, we see how a departmental culture and wider university infrastructure supporting commercial involvement began to emerge. As commercialization became more commonplace and acceptable for academic scientists, the meaning of entrepreneurship took a different form. One particularly important aspect of this process was the changing definition and use of research funds, that evolved as entrepreneurship took hold. We begin with a series of possible explanations for individual participation, turn next to structural factors that speak to collective enrollment, and then address how entrepreneurial activity changes over time as new norms of practice ramify across the department.

Individual-Level Factors

The canonical account of scientific advantage stresses the phenomenon of increasing returns, in which those who have early success are subsequently rewarded. This process of cumulative advantage suggests that certain scientists are better positioned to parlay their work into the commercial realm, and mobilize their resources and contacts to generate science that is of commercial importance (Merton, 1968; Levin & Stephan, 1991). Thus, faculty who are advantaged in the realm of science will be able to convert that position into the world of technology. These scientists have more resources, technicians, students, and postdocs to advance their research enterprise, publish more frequently, and have a larger corpus of science to draw upon. Hence, *faculty with more research funding should have more opportunities to patent, and will invent more frequently.*

Research support alone may not be the whole story, however. The propensity to patent may depend on contacts that influence how a scientist perceives commercial activity. The normative structure of science in the 1970s and 1980s was not altogether hospitable to commercial involvement (Bok, 1982), and the Mertonian ideals of disinterestedness and skepticism cast a broad influence (Merton, 1973). Thus, scientists may have needed contact or exposure to industry in order to be persuaded of the value of patenting. Scientists with industry funding or who consulted with industry may view commercial involvement differently from those who lacked such contacts, and may have more opportunity to be involved in downstream development of basic science. This exposure to the commercial world should heighten the propensity of these scientists to disclose their inventions. Consequently, *faculty with contacts in industry are more likely to be inventors.*

One common explanation for entrepreneurial efforts involves the incentives that attract scientists to engage with industry (Lach & Shankerman, 2004). Viewed in this light, pecuniary motivations pull scientists into the commercial realm. Thus, *the financial rewards of private science prompt faculty to disclose, and provide positive reinforcement to continue to do so as their research develops.* One might expect that scientists are primarily attracted to commercial science for its financial rewards. Furthermore, *those scientists who are successful in garnering significant licensing revenues are most likely to persist in entrepreneurial engagement.*

Work Context

The organization of modern science is strongly shaped by structural factors, including the context of laboratory life, the career ladder of the academy, and patterns of recruitment and reward within departments and, more broadly, inside the university. Most large-scale research activity in the life sciences occurs in laboratories that involve faculty, postdoctoral fellows, graduate students, and research and technical staff. Seen through this organizational lens, disclosing is rarely a solitary act, but shaped by

membership in a laboratory. Thus, we expect *inventors to be less likely to disclose on their own, and more likely to do so through collaboration with other members of their laboratory.*

Furthermore, much of the career structure of contemporary science is based on seniority, in which authority and rewards accrue as one moves through career stages. More senior scientists mobilize research teams to pursue questions and problems that build a program of research. This career structure influences inventing by linking newcomers to established senior scientists who are directors of laboratories. Hence, we anticipate that *new inventors are more likely to invent as part of a team headed by an experienced inventor, rather than with other inexperienced scientists.*

To the extent that career patterns shape the autonomy and discretion of scientists, one might anticipate that the spread of an activity such as inventing occurs through distinct career stages. For example, expansion may occur as structurally equivalent individuals engage in comparable activities because of peer comparison and competition (Lorrain & White, 1971; Burt, 1987). This argument suggests that *inventors are likely to become enrolled in commercialization as others at a comparable career stage do.* Nevertheless, to the extent that commercial involvement with industry is novel, unfamiliar, and frowned upon, one might expect only those scientists who are secure in their status to participate (Philips & Zuckerman, 2001). Scientists seeking to gain tenure or in the early stages of their career would be reluctant to engage in such an activity. Thus, *when commercialization is new or departs from established practices, those most likely to pursue it should be established senior faculty.*

Period Effects

We have argued that academic entrepreneurship developed gradually, rather than abruptly, and evolved in stages. As commercial engagement became more frequent among scientists, the perception of the activity acquired a different tone. Commercializing research results became regarded as legitimate, the activity became institutionalized, and the reputations of engaged scientists were enhanced rather than threatened. In previous work, based on a close reading of Office of Technology Licensing (OTL) archives, we established three time periods that take into account both the institutionalization of technology transfer at Stanford and the larger federal policy changes buttressing the commercialization of science (Colyvas & Powell, 2006). In the early years, from 1970 to 1980, venturing into the unfamiliar territory of commercial engagement involved risks, notably to one's academic reputation, as entrepreneurship was perceived as possibly eclipsing one's duties as a faculty scientist. Such activity ran counter to many of the norms of science. Decisions to commercialize were characterized largely as an exception rather than the norm. In the middle period, 1981–1993, commercial involvement became more accepted, though it was still a subject of debate and contention. While universities were afforded the legitimacy to transfer technologies, concerns over conflict of interest for individual faculty were amplified as many forms of science were being patented for the first time. By the mid-1990s, the marketization of science became not only routine for both the university and scientists, but was celebrated as a marker of success. Accordingly, our third period runs from 1994 to 2000.

Consequently, we expect that, *in the earliest period, accomplished, high status scientists are more likely to disclose inventions.* These senior scientists have earned their spurs in the world of scientific competition and have well-established laboratories. They are thus less vulnerable to charges that their work has been tainted by involvement with industry or concerned about promotion. In period two, *as commercial involvement became more legitimate, we expect inventive activity to spread first to other senior faculty.* Having obtained tenure, more senior scientists will be susceptible to pursuing commercial opportunities or open to university requests to fulfill national mandates to transfer technologies for public use and benefit. In period three, *we expect commercial involvement to permeate into earlier, pre-tenure career stages.* As controversial cases are adjudicated and success is garnered by others without damage to reputation, the unfettered ability to pursue commercial endeavors will attract early career scientists. Entrepreneurship becomes an identity in the academic context in which doing business with industry signals acumen and success.

High-status scientists, however, are not the only individuals susceptible to commercialization. As mentioned earlier, the research process is highly collaborative and the structure of academic science involves students and postdocs. The extent to which one may participate in commercialization is contingent on research networks and laboratory membership. Students and postdocs are not always in a position to pursue or resist patenting independent of their faculty supervisors. We expect *students and postdocs to be involved in patenting only through the collaboration with high-status faculty.* As more senior faculty become involved in period two, postdocs and students will be more likely to disclose as well. In period three, *we argue that early career scientists will be more likely to disclose independently of a high status collaborator.*

TECHNOLOGY TRANSFER AT STANFORD UNIVERSITY

Stanford is an auspicious site to observe the emergence of technology transfer as entrepreneurial efforts occurred when commercializing academic science was both new to the university and to the wider setting of the academy. Stanford began a technology transfer program in the summer of 1968, well before federal legislation in the early 1980s mandated such efforts (Colyvas, 2007). Stanford subsequently became one of the most successful technology transfer offices, frequently touted as a model for emulation by many U.S. and foreign universities.

Our focus is on the life sciences where commercial involvement was new. In the late 1970s and early 1980s, the biotechnology field was just emerging. In addition the scientific status of this discipline underwent a transformation in the 1980s, opening up novel opportunities for collaborations with researchers in other basic and clinical fields. Our time periods afford us the ability to observe the early to late stages of an important change, as entrepreneurship developed and became commonplace to university science.

Our case is a single department in the Medical School, albeit among the best funded and most prestigious. Most senior faculty were members of the National Academy of Sciences. It was among the earliest basic science departments in the Medical School, founded in the 1950s by a Nobel Laureate charged with the task of building a first rate basic science program. While small in terms of number of faculty, it was considerably better funded than other basic science departments in the Medical School. The department remained relatively small through the 1980s, making mostly senior hires. In the 1990s, with the appointment of a new chair, it grew quickly, adding junior positions. Even though a small unit, the inventive activity of this department is significant. Over this 31-year period, its members produced 130 patents. While the number of disclosures may seem modest, consider the activity relative to the small size of this department and in comparison to other universities. The level of activity at Duke and Johns Hopkins Universities in the biomedical field in the 1990s was no greater than at Stanford in the 1970s (Bercovitz & Feldman, 2005).

Data Sources

We utilize data derived from electronic and archival sources at the university, supplemented through proprietary search databases, and the World

Wide Web.[2] We focus on the activities of individuals associated with this basic life science department, as well as any co-inventors from other departments or outside the university. The criterion for being considered an inventor is whether an individual has submitted an invention disclosure to the Stanford OTL for consideration to be patented or licensed. In the sample, there are 179 disclosures, or inventions, between 1970 and 2000, and 198 individual inventors. There are 474 incidences of inventing, counting inventors for each individual act of disclosing. Clearly, most disclosures have multiple inventors. For purposes of constructing the sample, we include only those inventions attributed to an inventor while he or she was affiliated with this department.[3] Disclosures by inventors when they held appointments in other Stanford departments (e.g. a faculty member who had been a graduate student or professor in another department) are not included in the sample, nor are inventions by faculty when they were at other universities or working outside the university. We include in our analysis any prior record of disclosing as an indicator of an individual's previous experience.[4]

We coded the attributes of individuals, such as affiliation and job title, at the time of each disclosure, and recorded the revenues generated by each invention that is licensed.[5] As a check for inventive activity that may not have been captured through disclosures, we searched the names of inventors and non-inventors in our sample through the United States Patent and Trademark Office database. We obtained assignment information for each patent, noting whether it was owned by Stanford, an outside academic institution, or a company. While some faculty who disclosed at Stanford also held patents with other organizations, we identified only one case of a Stanford non-inventor with a patent from outside of the university; this occurred when he was a graduate student at another university. In addition, we matched our names against a dataset of biotechnology founders in the Silicon Valley and Boston regions between 1969 and 2002 (Porter, 2004). None of our non-inventors appear as founders, and no new incidents of entrepreneurship among our inventor sample were identified. Finally, to account for the size of the research laboratories and source of support, we collected annual data on faculty members' sponsored and contract research expenditures, collected through the Stanford Office of Sponsored Research. In return for access to these data, we agreed to provide anonymity to the department and its members.

This rich dataset has limitations, however, that reflect how complicated it is to construct a sample of all individuals who engage in entrepreneurial activity. We have rather complete data on those individuals who disclosed inventions. For inventors who are faculty members of the department, we can contrast them to the full population of faculty in the department, which

we were able to construct with university records. We do not have, however, comparable data on the full departmental population of students, technicians, postdoctoral fellows, or other scientific staff, as no complete records exist of who was present at the time. Thus, we know a good deal about those who filed disclosures, have less information about faculty and students in the department who never disclosed, and very little information on other staff in the department who did not invent. When we turn to outside collaborators – whether within the university or in industry – we lack comparable data. Looking at a 31-year period allows us to see how inventive activity changes over time, but adds in the complications of students and staff who depart, faculty who are hired, promoted, or change affiliations. In short, the statuses of our inventors are not constant, and we have to make judgment calls as to how such changes influence commercial engagement.

Because we have a single influential department and a relatively small number of inventors, we present our data in the form of a case rather than with inferential statistics. We do not adjudicate, for example, as to whether a scientist with considerable research funds is more likely to engage with industry on her own, or be pulled into involvement by industrial counterparts that want to exploit her research. Instead, we draw on the archives, specifics of inventions, and departmental context to supplement the data and address the expectations derived from the literature.

FINDINGS

In broad strokes, entrepreneurship, measured by the number of disclosures and number of inventors, increased over time, albeit in fits and starts. Figs. 1(a) and (b) track inventors and disclosures over the period 1970–2000, charting both number and cumulative growth. These figures illustrate the scale of inventing within this department. Fig. 1(a) shows that the overall shape of inventive activity is somewhat bimodal, with an early bump from 1978 to 1982, a subsequent decline, then an increase in 1993 and 1994, with rapid expansion in the late 1990s. The number of inventors exceeds the number of disclosures, especially so in the 1990s, reflecting either multiple authors appearing on an invention or a single prolific inventor with numerous disclosures.

Within the academy, publishing is highly skewed, as a small number of scientists contribute a disproportionate share of the output. It is not surprising then that inventing, especially in the early years, is similarly concentrated. There are relatively few inventors initially, and not until the mid-1990s does the number of inventors in the department exceed 20 annually. Fig. 1(b) plots

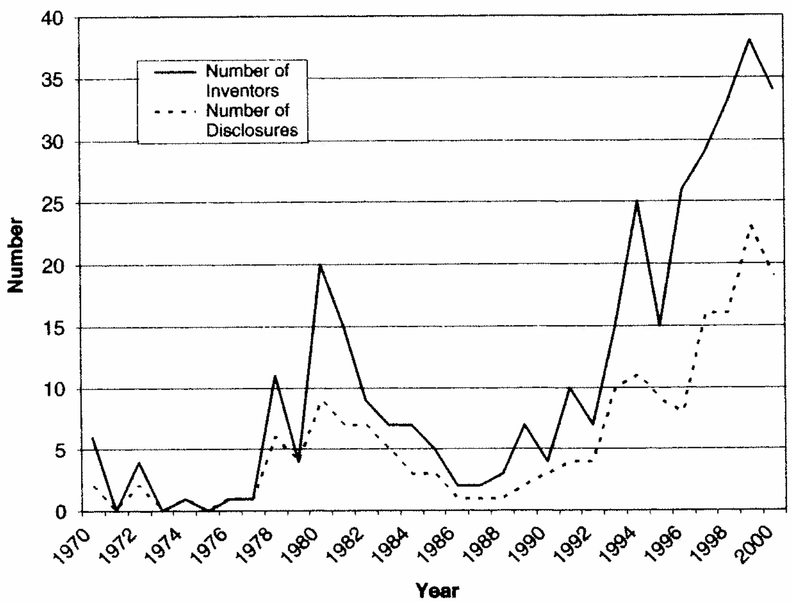

Fig. 1(a). Number of Inventors and Disclosures, 1970–2000.

the cumulative growth of disclosures and inventors. We see that the number of disclosures grew in the early 1980s, then declined through the end of the decade, and rose sharply throughout the 1990s, while the number of inventors mushroomed as well. These figures show that, overall, inventive activity is expanding, and there are distinct stages of development.

One common explanation for academic entrepreneurship relates to the federal policy changes that took place in the 1980s. These changes might be expected to be associated with an increase in disclosure activity. Our data, however, reflect a different trend – a decline through the 1980s, precisely in the wake of legislation that sought to encourage such efforts. This disparity underscores an important distinction between the socio-political form of legitimacy afforded to universities at this time by legislation, compared to a lag in cultural-cognitive legitimacy among individual scientists (Aldrich & Fiol, 1994; Colyvas & Powell, 2006). While technology transfer became a justifiable and politically approved activity, the convention had not yet taken hold in the life sciences community and was still subject to considerable debate and contestation.

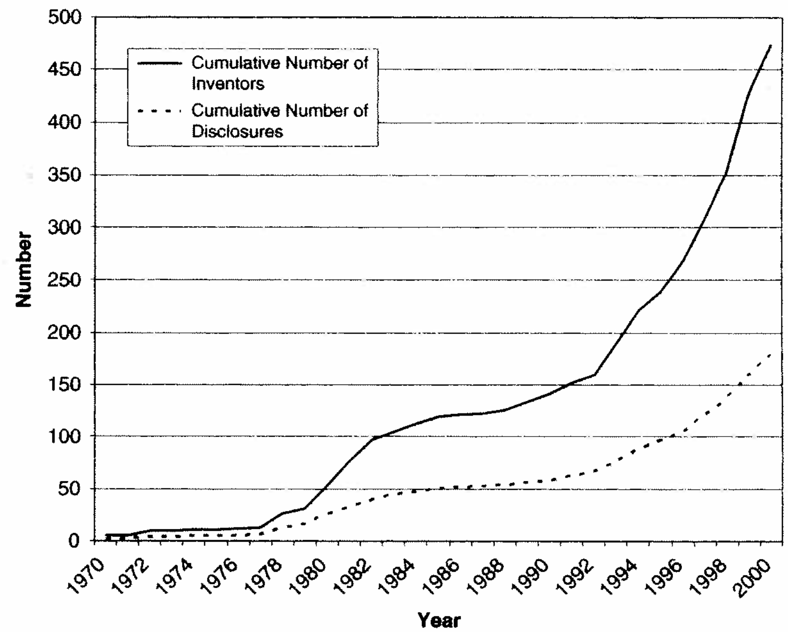

Fig. 1(b). Cumulative Number of Inventors and Disclosures, 1970–2000.

The archival records from the 1980s are replete with examples of such ferment. Although a few professors wanted to become more involved with faculty start-up companies, the rules about conflicts of interest were still being worked out. At Stanford, and other universities, questions about whether faculty could have equity in a start-up, and how much time could be devoted to a company, prompted much discussion between the higher administration, the university's legal office, and entrepreneurially inclined faculty. Faculty who submitted an invention disclosure and then wished to obtain an exclusive license for their own company were inhibited or required approval from the higher administration. There was some concern that enterprising faculty might be circumventing the university and commercializing their findings elsewhere. Indeed, a close examination of the disclosure data finds that one faculty member who disclosed an invention during this period left soon after to start a company. Another faculty inventor in the department temporarily ceased disclosing inventions to the university in the mid to late 1980s, as issues of conflict of interest were being sorted out.

Table 1. Rank at Time of Invention 1970–2000.

	1970–1980	1981–1993	1994–2000	All Years
Faculty	31%	44%	48%	45%
Postdocs or fellows	13%	12%	10%	11%
Students	6%	15%	20%	17%
Scientific or technical personnel	46%	19%	11%	18%
Scientists at other universities	4%	8%	9%	8%
Scientists at companies	0%	2%	2%	2%
Number of individual cases of disclosing	54	137	283	474

This eminent scientist did not, however, apply for patents on his own or with a company during this hiatus. As policies became established in the early 1990s and the campus patenting policy in 1994 was settled, we see broader acceptance of commercial involvement, with more new inventors and repeat disclosing activity by prior inventors, signaling cultural-cognitive legitimacy.

This shift in acceptance is reflected in the numbers in Table 1, which lists inventor rank at the time of a disclosure. We present the data by time period, and the period effects are notable. There are 54 cases of individuals disclosing from 1970 to 1980 (including multiple inventors for each invention and repeat activity of the same inventors), 137 from 1981 to 1993, and 283 in the short seven-year window of 1994–2000. This table captures several key trends. Note that from 1970 to 1980, inventing was primarily done by scientific or technical staff. Less than a third of the inventions listed faculty as inventors. In period two, we see a marked change, as technicians are no longer commonly listed on disclosures, and faculty participation rises. Student involvement more than doubles. Both faculty and student engagement rise again in period three, as technicians' participation continues to decline. Thus, as disclosing inventions expand, it permeates into the academic ranks and travels down the career ladder. Clearly, inventive efforts are no longer the province of the technical staff and become much more common among faculty, and some students.

Interestingly, there is some collaboration with scientists outside the university, but primarily those at other campuses, not with scientists at companies. There is no evidence in the archival records that industry science pulled faculty into inventing. In contrast, as we shall see below, there is much more of a push factor, as a small number of faculty assigned their inventions to companies that they were closely involved in consulting with or founding.

Attributes

We turn now to look at the characteristics of faculty in the department. The work context in the life sciences is a laboratory, headed by a faculty member. We present the data by periods, as we find this partitioning most indicative of the changing patterns of involvement. One set of explanations for entrepreneurship stresses the characteristics of scientists, notably their resources, experience, and contact with industry. Table 2 is the first of three tables that provide insight into how these factors influence disclosing. Faculty are represented by letters to preserve anonymity, and arrayed chronologically by the year they joined the department. We list the number of disclosures they make in each time period, their cumulative number of disclosures, and annual research expenditures of each faculty member. Note that average expenditures were calculated by the sum of all contracts and research grants attributable to each individual, divided by the total number of years in which a faculty member had research awards. In some cases, faculty were Principal Investigators (PIs) for research grants that were administered in other units in the university and these data were included in the total calculations. We also ascertained the amount of funding faculty received from industry. We consider the annual research expenditures as an indicator of the scale and prestige of a faculty member's research program, and corporate funding as one measure of contact with industry.

We also list the number of disclosures that were successfully licensed, and the gross revenues generated by these disclosures. The latter sum is an indicator of the commercial success of an invention, and certainly a measure of a faculty member's status as an inventor. But this total figure is not indicative of a faculty member's monetary share. The university takes a 15% cut, and then royalties are split by thirds among school, department, and inventor.[6] With multiple inventors, the share is further subdivided.

Only three faculty out of nine who were in the department over this entire decade were involved in disclosing. Two prominent senior faculty are responsible for the lion's share of the activity. This table does not list students, postdocs, or technicians, but we know that the non-faculty staff that were active in disclosing during this period came largely from these two laboratories. Disclosures by faculty did not occur until fairly late in the 1970s, and only five of the 11 faculty disclosures were successfully licensed by the OTL to companies. With respect to arguments about propensity to disclose, there are several key considerations, including funding, industry contact, and reward. We take up each in turn.

Table 2. Invention Disclosure Activity, Research Expenditures, and Returns to Licensing, 1970–1980.

Faculty	Year Joined Department	Number of Disclosures/ Cumulative Total	Year of First Disclosure in Department	Average Annual Research Expenditures	Year of First Industry Funding	Total Experience in Industry Sources	Number of Disclosures Licensed with Income	Gross Revenues from Disclosures[a]
Professor A	1954			$1,272,793	1975	$9,087		
Professor B	1960	4/4	1978	$702,929			2	$23,064
Professor C	1963			$142,224				
Assoc. Prof. D	1966			$93,741				
Professor E	1972			$197,240				
Assoc. Prof. F	1974			$52,603				
Asst. Prof. G	1977	1/1	1980	$173,761				
Professor H[b]	1977	6/8	1978	$729,047	1977	$24,333	3	$106,500
Asst. Prof. I	1980							

[a]These are total dollars received by the university, which is shared among the school, department, and inventor(s) after a 15% overhead is deducted. Note that the inventor 1/3 is split among the total number of inventors. Recall that solo inventors are infrequent (15%).
[b]This faculty member had two disclosures prior to joining the department, the first in 1973.

In this early period, Professors A, B, and H had sizeable research budgets. Professor A, the department chair, had the largest, not surprising given his tenure and stature as a Nobel Laureate. But he never invented. Professors B and H had generous research support, and their laboratories became the initial centers of enterprising efforts in the department. Large research budgets allowed faculty to have more technical staff, support more postdocs and graduate students, and expand the scope and intensity of their research programs. Neither faculty member earned much money during this period, so pecuniary incentives had little force. One might argue that the anticipation of income may have been a factor in motivating faculty to disclose. This claim is weak considering that few faculty disclosed during this period and that the market potential for biological invention had not yet been demonstrated at the university. Professor A's disclosure was one of the first from a life science department and the industry scientist who was involved in the work lamented that there was no current market for the technology. Similarly, Professor H initially declined to disclose his basic research findings. Only after the considerable solicitation by the OTL did this scientist agree, persuaded by the argument that doing so would accelerate application into biomedical therapies and protect the technology from being privatized by industry.

Industry funding does not appear to carry much influence, either. Professor A has some modest funds but does not disclose, and Professor B discloses without any industry contacts. There are, to be sure, other kinds of contact with industry, such as involvement with start-up companies, serving on scientific advisory boards, and consulting relations. The archival records of the OTL point to a sharp distinction drawn between consulting with companies and licensing scientific results. In the 1970s, the former was common, while the latter was unusual (Colyvas & Powell, 2006, 329–37). The department chair, Professor A, consulted regularly with companies as early as 1970, and was receptive to contact with industry. The first two disclosures in the department, made by technicians in 1970, one for a chemical synthesis of a hormone and the other for a device, were both submitted with the encouragement of the department head. Indeed, the leadership of the department was very entrepreneurial. The founder of the department was among the first to bring artificial intelligence and computing to biomedical research, developing a famous venture with a faculty member in the computer science department in the mid-1960s that was commercialized. The next Chair, Professor H, took the reins in 1978 and he had developed a software consumer product in the early 1970s related to biomedicine, that involved the founding of a company to distribute and provide technical support. Neither effort involved patents, though the latter was administered through the OTL.

Consequently, the evidence on industrial influence is mixed. Based on the relatively scant corporate research support, we do not see signs that disclosing was strongly influenced by industry funding. Nor is there any indication for the faculty that consulting with industry led them to disclose their research findings, as neither Professor B nor H had such a relationship at the time of their first disclosures. None of these faculty appear to be involved in biotechnology ventures during this time, although faculty H's invention drew the attention of a local start-up that hired him to consult, and to which he assigned one patent toward the latter part of the period. But prior contact with industry does appear consequential at the department level, as the earliest chair of this department consulted with local biotechnology companies even though he never patented nor disclosed an invention. The archives and interviews with his contemporaries suggest that Professor A perceived involvement with industry and other disciplines as beneficial to the expansion of science and was credited with making early exceptions to commercializing Professor H's technology possible. While department chair, Professor A recruited Professor H to the department, and his arrival added an established inventor and consultant to the ranks.

We turn to the second period, 1981–1992, when licensing the results of academic research was now encouraged, indeed mandated, by federal legislation. As we mentioned earlier, these policy changes had little immediate impact on this department at Stanford. There are several possible reasons for this. One, Stanford was a 'first-mover' and some faculty were engaged in enterprising efforts well in advance of the federal law. Two, the National Science Foundation and National Institutes of Health had developed institutional patent agreements already in the early 1970s with Stanford and several other universities, making it easy for the OTL to obtain title to life science inventions. Thus, the new legislation changed little procedurally for the life sciences. Three, university restrictions on investing in or licensing to faculty-owned start-ups discouraged the most active form of entrepreneurship. Finally, with respect to this department, the unit remained rather small until 1989, when 11 new faculty members were added rapidly over a four-year period. Among the 11 were two senior faculty who were already prolific inventors.

One policy event, however, may have had some significance when examining the types of technologies being disclosed. Breakthroughs in biological materials such as monoclonal antibodies, coupled with the *Diamond versus Chakrabarty* Supreme Court ruling, opened up a range of scientific artifacts

that could be patented and commercialized. The university became enmeshed in a whole new set of debates around "tangible research property," and whether biological materials required licenses when distributed to other researchers. One faculty member argued such materials should not be patented and personal income from their dissemination was inappropriate. Others expressed anger that industry was profiting from federally funded and university-derived research (Colyvas, 2007). The policy was settled in the early 1980s, leaving open the question of whether or not one chooses to patent. While biological materials for research purposes would be openly disseminated, licenses would be required for commercial use. As a result, the number of biological materials being disclosed increased markedly from the previous period, as did the frequency of inventing within individual research programs.

This period was significant for the department. Not only did it expand in size, but two notable inventions returned considerable revenues to the department. As is clear from even a cursory look at Table 3, many more faculty were disclosing research results, research funding to the department increased, and revenues from licensing were flowing into the unit and to a small number of senior faculty. We take up these changes in turn.

In the previous period there were two active inventors, both continue their enterprising efforts in the 1980s. Professor B has 17 disclosures between 1981 and 1993, and Professor H has 10. They are joined in 1989 by Professor C who discloses nine times in three years, and Professor O in 1991 who has eight disclosures in 1993 alone. There is now a quartet of senior professors who are very entrepreneurial. Their influence is considerable as other senior faculty disclose for the first time during this period, and several younger faculty get involved as well.

Research budgets mushroomed in the 1980s, as six faculty had annual research expenditures in excess of $1 million. Nevertheless, two of these faculty – Professors N and T – did not disclose, and Professor E did so only once. Industry funding remained rare, but Professor B worked with a company that was developing his research tool and this contact results in corporate support to his laboratory. All faculty continued to assign their patents to the university, save for Professor H, who assigned six of his nine patents to a local biotech company where he consulted, and Professors N and O who were newcomers to the department and brought with them six and eight previous industry patents.

As in the previous era, contact with industry did not appear to predict first-time engagement in disclosing, but was important at the leadership level and reinforced the appointment of entrepreneurial faculty to the

Table 3. Invention Disclosure Activity, Research Expenditures, and Returns to Licensing, 1981–1993.

Faculty	Year Joined Department	Number of Disclosures/ Cumulative Total	Year of First Disclosure in Department	Average Annual Research Expenditures	Year of First Industry Funding	Total Experience in Industry Sources	Number of Disclosures Licensed with Income	Gross Revenues from Disclosures[a]
Professor B	1960	17/21	1978	$1,277,058	1982	$259,773	8	$1,390,775
Professor D	1966			$122,102				
Professor E	1972	1/1	1989	$1,025,532				
Professor F	1974			$104,512				
Asst. Prof. G	1977	1/1	1980	$137,048				
Professor H	1977	10/18	1978	$1,026,267	1977		8	$73,721,969
Asst. Prof. I	1980	1/1	1982	$147,624				
Asst. Prof. J	1982	1/1	1984	$268,671				
Professor K	1989	2/2	1992	$378,996			1	$10,000
Professor L	1989	9/10	1990	$305,141			1	$295,500
Assoc. Prof. M	1990		1990	$528,672				
Professor N[b]	1990	0/2		$1,002,190			1	$110,000
Professor O	1991	8/10	1993	$1,769,314			6	$942,551
Assoc. Prof. P	1991			$249,224				
Professor Q	1991			$503,707				
Professor R	1992			$460,142				
Professor S	1993							
Assoc. Prof. T	1993			$1,668,133				
Assoc. Prof. U[b]	1993	0/2					1	$723,173

[a]This faculty member had two disclosures as a student in a different department in 1986 and 1987.
[b]This faculty member had two disclosures in 1979 and 1980 prior to joining the department.

department. Professor N arrived during this period to serve as chair of the department after several years as a chief scientist at a biotechnology company. Professor O, his collaborator, joins from another Stanford department. Again, the department Chair's proclivity toward industry is neither reflected in disclosures to the university nor start-up activity as he never founded a company. Like Professor H, Professor O continued to disclose to both the university and patent in industry, suggesting the ability of some faculty to create boundaries between their university and industry work.

Within the department, there were numerous successful licenses – 28 are assigned to companies and generate revenues. This is a remarkable development in several respects. One, financial reward did not flow back into the department or to the inventors quickly. With the most lucrative licenses, those from Professors B and H, it took five years after disclosure before any revenues were received. This lag did not stop them from continuing to disclose, however. Two, this record of success is unusual because technology transfer is so highly uncertain. Consider that of the 179 technologies disclosed in this department, only 30% generated any revenues by 2000. Of those 54, 13 earned more than $100,000 and only four more than a million. Two of those four were licensed in period two. The department had the good fortune of having two early blockbuster successes, accomplishments that many other departments and universities have never had. For example, in 2000, Stanford earned $41.2 million in gross revenues from 371 inventions. Only 47 generated revenues over $100,000, and but seven of these earned more than one million (Stanford OTL, FY2000–2001). This department, then, was very much stamped by the early successes of Professors B and H, and the arrival of new faculty who proved to be enterprising and successful as well (Stanford, 2001).

It is important, however, not to overstate the pecuniary side of this success or underemphasize the resource aspect. Professor B did not accept licensing revenues personally, asking that money be signed over to his laboratory. Professor H initially donated his share back to a research and training fund, also declining any personal gain from his invention. The amount reported for gross revenues in our table is the total received by the university. Recall that after the university takes a 15% cut, the shares are divided equally among the school, department, and inventors. So a very sizable sum of money flowed back to the Medical School and the department. In turn, the department was able to expand by adding new faculty, and laboratories grew much larger too. Here, we see the process of cumulative advantage at work, as both faculty and the department have considerable resources to draw on to advance research programs.

Turning to the third period, 1994–2000, (Table 4) the high-profile faculty that joined in the early 1990s with established track records of engagement with the biotech industry proved to be consequential. Professors O and N both had disclosures at the university as well as patents with external companies, although Professor N does not disclose to the university for 8 years. The spread of entrepreneurship was thus shaped by these new entrants, as well as adoption by incumbents. Both processes are clearly influential. Every faculty member present during this period that was hired between 1960 and 1993 disclosed by 2000. Of those hired between 1995 and 2000, four disclosed during this time period. We see that disclosing inventions has become a routine activity, with Professors B, J, L, N, O, Q, and AA especially active. The ramifications of this activity are apparent in several ways. Nine faculty had annual research budgets exceeding $800,000 annually, and nine faculty had licenses that brought in more than $100,000 to the university. The department and school garnered significant income as faculty invention portfolios, such as Professor H's, generated considerable commercial interest.

Two other changes occured during this recent period. One, entrepreneurial activity is no longer the province of either esteemed professors or non-tenure track scientists. Associate professors and assistant professors became involved, some with considerable success. Here we see again how entrepreneurial activity permeates down the ranks, involving a greater number of faculty at all levels. Two, involvement with industry became more common, and new hires were much more likely to have those contacts. Moreover, much of the contact came in the late 1990s. While only two faculty – Professors O and S – garnered significant industry funding, collaboration with biotechnology companies clearly increased. Professor O's contract with a biotechnology firm was for a project funded by a government agency. Professor S's contract came from an industry–government–academic consortium that coordinated a multi-organizational discovery effort. Consider also that the research results of this enterprise were made available for public dissemination, and the patenting of the results was restricted. Thus, an important transformation began to take place in which industry, government, and the academy were increasingly interlinked at the frontiers of science (Powell & Owen-Smith, 1998; Vallas & Kleinman, 2006). Rather than industry pulling faculty into the world of commerce, it appears industry and government were drawn to the fundamental science conducted in the department.

We supplement the data on faculty funding and licensing with a look at the first-time experiences of inventors. In the database, there are 78 incidences of first invention, all other disclosures are by repeat inventors. We have emphasized how much biological research takes place in the context of

Table 4. Invention Disclosure Activity, Research Expenditures, and Returns to Licensing, 1994–2000.

Faculty	Year Joined Department	Number of Disclosures/ Cumulative Total	Year of First Disclosure in Department	Average Annual Research Expenditures	Year of First Industry Funding	Total Experience in Industry Sources	Number of Disclosures Licensed with Income	Gross Revenues from Disclosures
Professor B	1960	14/35	1978	$1,649,630	1982		14	$8,108,002
Professor H	1977	2/20	1978	$1,091,632	1977	$160,640	5	$182,210,248
Assoc. Prof. J	1982	12/14	1982	$270,328	1996	$10,000	5	$493,725
Professor K	1989	4/6	1992	$217,438			1	$30,612
Professor L[a]	1989	14/24	1989	$644,284			8	$250,000
Professor N[a]	1990	8/10	1998	$2,692,489	1999	$326,498	4	$112,495
Professor O[b]	1991	15/25	1993	$9,648,716	1994	$926,589	9	$927,905
Assoc. Prof. P	1991	1/1	1997	$300,289			1	$28,500
Professor Q	1991	9/9	1994	$126,892			4	$136,000
Professor R	1992	4/4	1994	$907,094	1995	$226,445		
Professor S	1993	3/3	1995	$2,298,594	1999	$5,322,175	2	$47,500
Professor T	1993	3/3	1996	$6,599,653			1	$47,500
Asst. Prof. U	1993	1/3	1998	$308,858			1	$878,250
Asst. Prof. V	1995	5/5	1995	$147,776			3	$103,000
Professor W	1995			$807,072				
Asst. Prof. X	1998			$188,692	2000	$2,678		
Asst. Prof. Y	1998	1/1	2000	$29,754				
Asst. Prof. Z	1998			$133,993				
Assoc. Prof. AA	1998	13/13	1998	$885,484	1999	$323,199	6	$41,073
Assoc. Prof. AB	1999	1/1	2000	$645,666	1999	$246,300		
Asst. Prof. AC	1999			$24,233				
Asst. Prof. AD	1999			$205,314				
Asst. Prof. AE	1999			$224,950				
Asst. Prof. AF	2000							
Asst. Prof. AG	2000			$201,461				

[a]These faculty members had two disclosures prior to joining the department.
[b]This faculty member had 7 disclosures prior to joining the department.

Table 5. First-Time Inventors, 1970–2000[a].

Characteristics	Frequency (%)
Solo inventor[b]	15
With co-inventor	85
With laboratory PI	56
With experienced co-inventor (two or more prior disclosures)	41
With financially successful co-inventor[c]	31
With higher status co-inventor	58

[a]There are 78 first-time inventors.
[b]Fifty percent of the solo first-time inventors were laboratory PIs.
[c]Defined as had previously earned $50,000 or more annually as an inventor.

research teams. Hicks and Katz (1996) have shown that publishing now routinely involves multiple authors, and inventorship has some parallels. We see from Table 5 that 85% of new inventors were introduced to disclosing by a colleague, while only 15% were solo inventors the first-time they disclosed. And of those solo inventors, half were the PIs of laboratories. This simple breakdown reinforces two points: one, academic entrepreneurship is seldom a solitary activity, and two, for those who do go it alone, seniority and reputation are critical credentials. We also suggested that newcomers to disclosing were more likely to invent with senior scientists, either the PI in charge of a laboratory or a more veteran scientist with prior experience with disclosing. This expectation that new inventors are introduced to entrepreneurship by more senior scientists is clearly borne out, with 56% disclosing for the first time with the PI of their laboratory, and 41% inventing with a veteran who had previously filed two or more disclosures.

There is less support, however, for the idea that newcomers turn not just to experienced inventors, but to those who have been financially successful. We coded revenue data and noted the point at which an individual received $50,000 or more in an inventor share from an invention. All subsequent collaborations after the year in which that sum was received were coded as co-inventions with a successful inventor. Only 31% of first-time inventors collaborated with scientists who had derived significant financial gain from their research. Much more salient is academic status. There is a pronounced trend for first-time inventors to attach to more high-status individuals. Fifty eight percent of the new inventors worked with scientists who were higher in rank, suggesting that younger, less experienced scientists were introduced to entrepreneurial efforts by more accomplished mentors, as inventing spreads to those more junior ranks in the academic hierarchy via sponsored

mobility. Thus, socialization and sponsorship are the primary mechanisms by which younger scientists are introduced to entrepreneurship.

Overall, presenting the information on faculty funding and disclosing in three distinct periods illuminates several key trends. In the early period, 1970–1980, the most frequent inventors were scientific and technical personnel. Indeed, while Professor B, who had one of the most active laboratories, was the senior author on all publications, he regarded it inappropriate to consider himself an "inventor," and reserved that status for his skilled technicians and engineers who developed the research tools (Colyvas, 2007). But the listing of technicians as inventors declines markedly, and faculty involvement increases, especially in the third period. By 2000, 17 of the 25 faculty in the department had disclosed (and examination of more recent records shows that three of the new assistant professors who joined in 1999 and 2000 had disclosed by 2002).

Faculty became much more knowledgeable about the opportunities that commercial activity posed for them. Consider this correspondence in the mid-1990s when a faculty member weighs options over whether to pursue his discovery through the university or on his own: "[Co-inventor] and I had decided to go 50-50 if we included both institutions…With Stanford in, [we] will see about 10 percent of the total." These professors are not just familiar with patenting their science, but demonstrate acumen in considering the complications of involving other institutions. Experienced scientists had come to understand the complexities of working with multiple universities in addition to licensing to companies, and the ins and outs of brokering commercial ventures. "We both recognize that we could be talking about percentages of nothing, but I don't think so. We probably should be making a proper deal in the first place."

By the late 1990s, as more research programs were directed by scientists with both experience and success at inventing, the message conveyed to new members of research teams and new faculty hires was that commercial activity was an appropriate complement to basic science. As entrepreneurship spread among senior participants and generated ample returns, those rewards were no longer viewed as exceptional but as components of routine professorial activity. Moreover, the revenues not only enhanced the inventors' financial circumstances, but greatly expanded the departmental budget, allowing more faculty and staff to be hired, and students to be funded, thus generating a new better-funded regime of knowledge production. Indeed, part of Professor N's agreement to leave a successful biotechnology company and assume the chair position included additional billets to hire junior faculty conducting cutting-edge research. A member of the National

Academy of Sciences and experienced in industry and academic science, Professor N returned to the academy to oversee the department's expansion. By the late 1990s, then, entrepreneurial efforts not only became conventional, they generated resources that were mobilized to bring in more talent to the department.

The 1990s also saw the frequent formation of academic-led biotechnology companies. A good deal of the scholarly attention of entrepreneurship researchers has focused on start-ups (Shane, 2004), and the biotechnology industry is well known for the considerable involvement of research faculty (Porter, 2004; Powell, 1996; Zucker et al., 1998). Our focus has been more on the antecedent activities that may eventually culminate in founding a company. In this department, as engagement with industry became a taken-for-granted feature of academic life, involvement in venture formation and start-up activity became commonplace. Examining the archives, patenting data and public records, we identified 10 faculty members involved in founding companies. Prior to the 1990s, such activity was rare. The new ventures formed before 1980 out of this department typically involved the university or an intermediary organization that disseminated application technologies that were not biotechnology related. Between 1980 and 1990, only two individuals started companies, and they left the university. By the early 1990s, conflict of interest policies became standardized. The university permitted exclusive licenses to faculty-owned firms and even came to accept equity from companies as part of licensing agreements. Hence, we see considerably more activity following the adoption of these policies. As Porter (2004) observes, faculty who founded companies in this era did not have to "quit their day jobs."

Network Formation

We turn now to visual representations of the network linkages among individual scientists affiliated with the department and their outside co-inventors between 1970 and 2000. These visualizations afford us the opportunity to expand beyond the faculty and include scientific and technical staff, graduate students, and co-inventors from other departments as well as from outside the university. These representations portray the full population of inventors associated with the department.

In Fig. 2 we visually represent the inventive teams with the nodes reflecting individual scientists and the lines representing linkages through joint invention disclosures. The individuals are coded by shape for career stage

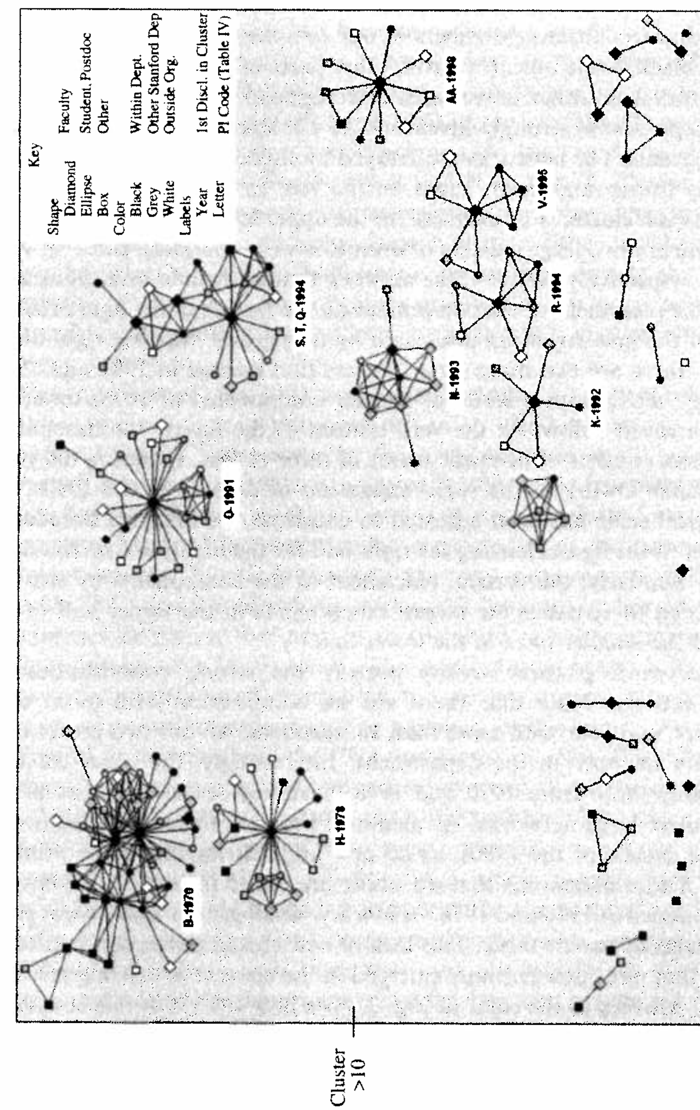

Fig. 2. Scientist Invention Networks, 1970–2000.

and 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 our sampled life science department are coded black, while inventors from other parts of the university are gray, and inventors from other universities or companies are white.[7]

Fig. 2 depicts how strongly inventors are clustered around particular research programs. The networks are arrayed by cluster size (vertical axis) and chronology (horizontal axis), based on the year in which a first invention appears in 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 network figures include inventions over all years, the placement of the component on the far left of the figure reflects the year of the first invention disclosure by that group. Moving right along the image, there are two more large clusters that emerge in 1991 and 1994, respectively, along with a series of smaller components of 10 or fewer individuals arrayed below. At the very bottom of the figure, the timeline of small clusters consists of inventor teams of three or less, spanning the years of the sample. Owing to the rapid expansion of activity in the 1990s, the chronological scale has been adjusted to condense the first two decades to the left half of the figure, leaving the right half for the highly active decade of the 1990s. Similarly, the vertical placement of the components by size has been adjusted to visualize the largest components in the upper half of the image and the smaller ones in the lower half.

These network pictures vividly portray the strong concentration of inventive activity. Note that there are six components with more than 10 members, and four with more than 18 members. All but two center on a core faculty member in the department. Interestingly, the older clusters, most notably those from 1970 and 1978, have key senior scientists at the center of these large networks. As mentioned earlier, there is limited invention in the decade of the 1980s, as no new large clusters developed during this time. Those inventions that do occur are either in one of the existing clusters founded in 1970 and 1978, or in a few small groups that do not grow beyond teams of two or three. This lack of new cluster formation reinforces the point that most new entrants emerged in the context of existing research programs. Moving to the right of Fig. 2, note how the 1990s reflect a sharp expansion of inventing and a second generation of inventive research programs. These mid-sized components cohere rapidly, rather than remaining small dyads or triads whose ties do not renew. The emergence of these clusters with multiple ties to internal and external collaborators further suggests the integration of entrepreneurship into faculty research programs.

Fig. 3 shows the invention clusters by time period, with the size of the node reflecting prior experience at disclosing. We picture 1980, 1993, and 2000, which captures the five-year windows at the end of each time period. The larger the node, the more disclosures the scientist has. Recall that even until the early 1980s, inventive activity was infrequent, thus the early clusters in the upper left-hand 1980 image are fairly sparse. Inventorship appears sporadic and disconnected, save for the dense clusters that eventually form around Professors B and H in Fig. 2. The largest cluster connects two collaborations with scientists from other departments. Note also the preponderance of technicians, inventing either in teams as in the upper left-hand side of the 1980 image, or on their own in the lower left-hand side. The students and postdocs involved in disclosing are connected to faculty, either within the department or through another Stanford laboratory.

Moving forward, the 1993 image demonstrates how much inventive activity in the previous period was driven by the laboratories of the two prominent faculty, represented by the larger triangles at the center of their inventive clusters. Professor B's cluster in the upper left-hand side of the image has multiple ties, as the group has reconstituted itself with more new inventions. Much of the energy in this second wave of disclosing came from a senior scientist in this laboratory who was promoted to full professor (Professor L) and who developed a research program on her own with nine disclosures in period two and 14 in the third, while continuing ongoing collaborations with Professor B. The small cluster below is Professor H, who is quite experienced, but his group does not expand with either repeat inventions or collaborations among members of the laboratory.

Several comments about the 1993 clusters are in order. Professor B's team continues to be very productive, pursuing work that extends the original innovation from this laboratory. Note the number of larger nodes in this laboratory group, reflecting how many members are now experienced inventors. Many of these collaborations renew themselves or generate new linkages as students and postdocs enter the laboratory. There is a great deal of repeated activity among the participants, suggesting a highly collaborative team, which generates multiple inventions. Some activity reaches outside of the department, but the majority is centered in this laboratory.

Compare this cluster to the contrasting group located just below. What had been a very large hub-and-spoke network organized around Professor H with outside collaborators, is now a triad, as this program did not sustain itself by enrolling new participants or with new collaborations with existing

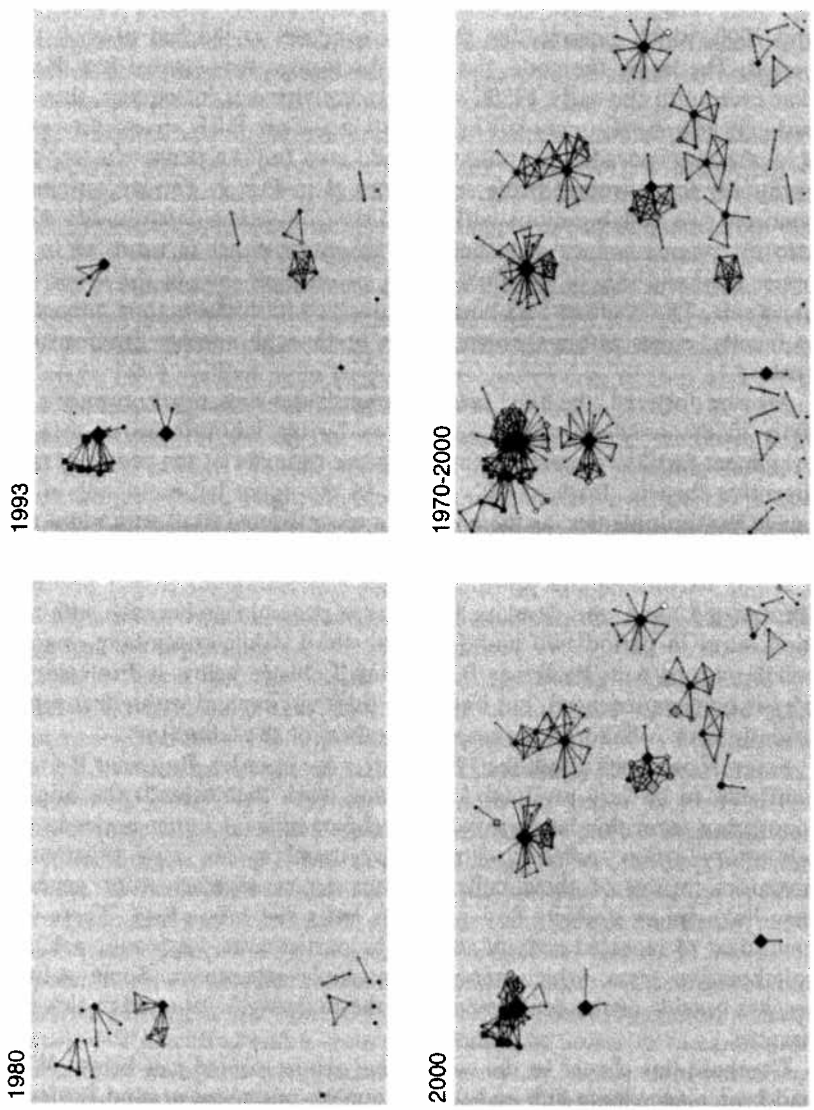

Fig. 3. Scientist Invention Networks with Node Size for Experience.

members. Inventorship in this laboratory relied on a central individual and never expanded to encompass interconnected teams. What the two clusters share, however, is an integration of inventing within the laboratory, as the external co-inventors (coded gray) from the previous era are largely replaced by ties within the laboratory (black) or to faculty outside the university (white). The few gray nodes are students or postdocs affiliated with other basic science departments who collaborate in these laboratories.

Moving to the right of the 1993 image, we see the emergence of a few new small to medium sized clusters. The only cluster in the upper middle image illustrates the appointment of a faculty member, Professor O, to the department who is already an experienced inventor. This professor brings in outside collaborations with two faculty colleagues from another university, depicted by the ties to the two white diamonds. Note again how the student and postdoc inventors in the 1993 image are all connected to a faculty member, either within the department or through work in the laboratories of other Stanford faculty. In the last year of the image, we see for the first time the emergence of a team of two students with no faculty member.

Moving ahead to 2000, notice the growth of new research programs, and an increase in the number of experienced inventors. There are now seven sizable clusters of inventing centered on one or more faculty members. The growth of these prolific teams of faculty, postdocs, students, technical personnel, and outside scientists has become the primary motor for the increase in entrepreneurial activity. Looking at the lower right panel, with the full 31-year period, we see 10 research clusters where considerable inventive activity takes place, with nine of these headed by an experienced inventor. Only one experienced inventor discloses in the context of a very small team, while just one star-shaped cluster does not have an experienced head. A number of the clusters are very sizable laboratories that have produced multiple inventions. Co-invention with other Stanford scientists (gray nodes) is common, reflecting the broadening of life science collaborations and ties to clinicians. Teams of students and postdocs become more common, although embedded in faculty clusters as in those of Professors N and S, T, and O. Note also the solo disclosures of students and postdocs in the lower left of the image and near the cluster of Professors S, T, and O. Finally, it is remarkable just how much the single slice from 2000 captures the broad outline of the summary picture of all years, 1970–2000, suggesting the prevalence of entrepreneurial activity is a relatively recent phenomenon.

The new appointments to the department fueled the expansion of these networks, as the experienced inventors brought industry ties and demonstrable success in the worlds of both public and private science. Indeed, there is considerable evidence that the department was reshaped by entry as much as adaptation. Recall that both Professors H and N were hired to the department with prior patenting experience to assume the roles of department chair. Professor O joined the department in 1991, bringing a laboratory with students and postdocs, as well as a sizeable $6.7 million research program. His entry is reflected in the largest cluster in Fig. 3. Professor AA joined in 1998 and developed the fourth largest inventive program of the 1990s. Professor Q, hired in 1991, and Professors S and T, who joined in 1993, came together to form an expansive cluster that links these three tenured faculty's research programs, combining Professor Q's ties to industry and private sector research support with Professor S's interdisciplinary ties and resources. The mid-1990s also reflect the emergence of clusters of entrepreneurship based on the efforts of more junior faculty, such as Professor V, whose more modest annual research expenditures culminated in five disclosures from 1995 to 2000.

SUMMARY AND IMPLICATIONS

The life sciences underwent a profound intellectual transformation in the 1970s and 1980s, as breakthrough discoveries facilitated new insights into the nature of diseases. In the department we studied, these tools attracted the attention of medical researchers from cardiology to neuroscience to urology, as massive amounts of novel information afforded deeper understanding of the mechanisms leading to diseases. In the context of this scientific revolution, the department expanded and senior faculty received significant federal research support. Given the excitement afoot in this field, it would be surprising indeed if there were not signs of entrepreneurial activity by members of the faculty, as both the newly emerging biotechnology industry and older pharmaceutical and medical instrumentation companies were attracted to these discoveries. Indeed, one sign of the normative power of the older communal, disinterested model of open science is the relative slowness with which entrepreneurship developed in the 1970s and 1980s, despite considerable interest in the work underway in this department by researchers in other departments and scientists in industry. Not until the 1990s did commercially engaged science become widespread.

We account for this general pattern in several steps. Our analysis follows the call of Aldrich and Ruef (2006), and spans multiple levels, connecting

individuals, research networks, the university, and the broader socio-political context. At the individual level, we see that contact with industry in the form of corporate support or revenues was inconsequential until the 1990s. Much more important was the scale of a scientist's research program, notably his or her research budgets. Well-funded scientists with numerous collaborators were more likely to disclose inventions precisely because they had a wider corpus of science and more human capital to draw on. Pecuniary incentives did not loom large in the early years, as the prospect of ample returns from entrepreneurship was unlikely. Most disclosures did not earn any money. By the 1990s, however, these odds changed markedly, suggesting that financial incentives were more an outcome than an input into the development of entrepreneurship. Once commercial opportunities became both visible and legitimate to pursue, industrial involvement comes to be regarded as another core aspect of high-powered science, integrated into career expectations. The pressures to publish, garner grants, fund students, and contribute to the frontiers of science and industry are considerable at a university like Stanford. Based on the disclosure records of this department, we argue that pecuniary considerations were less an incentive and more a part of a broad sweeping change in which public and private science were amalgamated in the 1990s.

To be clear, we are not arguing that financial success was inconsequential. On the contrary, rather than think of revenues as simply money, consider the ways in which commercial rewards reshaped academic science, often unexpectedly. In the case of the successful device from Professor B's laboratory, both the technical needs and opportunities for the laboratory facilitated more engagement with the company in order to develop the invention and eventually mass-produce it. As a result, numerous invention disclosures emerged. Initially, only technicians were inventors, but this group expanded from a small number of technical and research staff to include the principal investigator, co-authors, postdocs, and students. The size of the laboratory grew, fueled by grant money and licensing revenues. The number of inventors in this laboratory increased from 3 in 1970 to 18 in 1984, held steady at 14 in 1995, and rose to 20 in 2000. Many of the inventions included complimentary innovations that were part of the original device, including analysis software, further components of the apparatus, and biological tools and materials that improved the efficacy of the invention. Initially, returns on the invention were utilized to seed a facility that would make the invention available to the entire Stanford community for diagnostic and research purposes, borrowing the department share with the permission of the dean, and combining the funds with the inventor shares as capital to support this new facility. The financial rewards were employed in different ways over time, but always commensurate with the meanings ascribed to it by the inventors who were steeped in the evolving norms of academic science. One consequence of the commercial success for this group was that laboratory staff had more secure employment, students had access to better research equipment, and the PI became even more productive by the standards of normal science.

Furthermore, as public science was transformed and integrated with private science, so did the constraints and opportunities available to university faculty. Initially, licensing revenues were treated as gifts to replenish the laboratory, then as a means to build a public facility, then as resources to expand the department and the laboratory. While the inventors gained financially, of course, the key to their expansion, we argue, was the broad manner in which these gains were distributed.

Viewed more structurally, in terms of the social organization of laboratory life, the factors that influence inventive behavior were very much tied to the organization of university careers. Newcomers to the disclosure process were unlikely to invent alone; they entered by co-inventing with experienced inventors and/or the principal investigators of the laboratories in which they worked. This process of attachment highlights how much opportunities are shaped, as well as constrained, by whom one collaborates with. As much as newcomers may want to join with financially successful inventors, their ability to do so is limited by where they work. That said, commercial success certainly has many forms of appeal, ranging from resources, laboratory equipment, funding and employment opportunities to personal wealth. But in the context of the contemporary life sciences, such influences operate on young scientists more to shape their choices of which laboratory to go to and what topics to work on (Owen-Smith & Powell, 2001a).

Scientists who are averse to the new blending of public and private science are most concerned that the choice of topics by younger researchers is being shaped by considerations of commercial impact, and that important questions, with no immediate market prospects, are not being explored. Our analysis of the OTL archives and interviews with faculty and students suggest two perspectives on these concerns. To the extent that young scientists join in the context of established teams, then such worries are mitigated as research trajectories are established by the more senior laboratory director. Yet as entrepreneurial involvement becomes more widespread, there is some indication that younger scientists are much more inclined to search for "hot," marketable topics. In some respects, these ramifications are crucial for public health, as more work aimed at specific diseases is being pursued

with urgency. But at the same time, worry about the extent to which academic entrepreneurship makes science more market-driven also seems warranted (Nelson, 2005).

The expansion of entrepreneurial activity was very much conditioned by period effects. The 1970s were an initial era of ferment, and two research programs developed breakthrough technologies that attracted considerable scientific and commercial interest, eventually earning very substantial revenues from successful licenses. But these two laboratories remained the only games in town through most of the 1980s, even though federal legislation and public policy at the time encouraged academic entrepreneurship. The trend changed in the early 1990s, however, as new senior faculty with prior commercial involvement and impressive scientific credentials were brought into the department.

By the late 1990s, the transformation from inventing as a sideline activity pursued by technicians to a core activity by established, high-profile senior scientists was complete. Graduate students began to disclose as well, both with their mentors and occasionally with one another. Younger faculty joined the department and started disclosing inventions, either working solo or with other junior faculty. The network visualizations portray a department partitioned into numerous engaged, highly interactive clusters. By 2000, these inventive teams no longer required an eminent scientist to be at the center of each network. This shift co-occurs with a broader climate change at the university. Entrepreneurship became a venerated activity at Stanford, celebrated by an array of activities on campus and highlighted in numerous university publications. Consider the 2003–2004 Stanford OTL Annual Report "Celebrating Inventors" where prominent faculty inventors were featured and the office proclaims: "our success depends on the researchers whose passion drives the machinery of invention" (Stanford OTL, 2004). Courses such as "Invention 101" became common, fellowships and campus-wide entrepreneurship contests flourished, and university offices offered seminars on "How to be a Stanford Faculty Entrepreneur: Role Models and Resources."

This shift represents the culmination of a process in which entrepreneurship spread from two early "explorers" to other senior faculty of comparable status and then trickled down the career ladder to become an accepted activity of many life scientists. The identity of scientist entrepreneur became firmly settled and widely embraced, perhaps best summed up in the quip of a UC Berkeley professor that "I have this sense that it's an almost unwritten rule that you have to start a company to be a successful professor at Stanford" (Abate, 2006).

NOTES

1. We note below, however, that the norms of publishing and co-authorship did not readily transfer to disclosing and patenting.

2. These data are drawn from a larger project, comprising a systematic comparison of multiple departments at Stanford, that analyzes the development and diffusion of commercial involvement by faculty, students, and staff from 1970 to 2000 (Colyvas, 2007).

3. Of course, co-inventors can come from within or outside the department or university.

4. Note that an extension of this dataset was utilized in an earlier study where we included all inventions of the external scientists that were co-inventors, thus there is a larger total number of inventions in that analysis (Colyvas & Powell, 2006).

5. The main source for these data is the OTL electronic database and filed archives, which together generate a list of invention disclosures and their inventors. A list of names of individuals who had a reported affiliation with the sampled department was retrieved along with their co-inventors. As many faculty have joint appointments, and relevant longitudinal information such as job title or affiliation changes often over the 30-year period, university bulletins and electronic dissertation databases were used to determine whether individuals had a faculty or student affiliation with the department. This list was matched to the OTL list of inventors by hand, using file archives whenever possible to adjudicate among similar or abbreviated names, and organized into a relational database that documented career transitions (i.e. a promotion or departure from the university) at each instance of a new invention disclosure. These data were checked and supplemented through the World Wide Web, using the Google search engine and Google scholar to identify publicly reported affiliations through university websites, CVs and scholarly publications.

6. Initially, Stanford's policy was for the School's share to go to a general university fund. After extensive debate and protest from the Medical School, and by a professor from this department in particular, the policy was changed in the early 1980s to divert the general university share to the Medical School (Colyvas, 2007).

7. 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 for a duration of five years, beginning with the year of disclosure, and the 'generate in time' function in Pajek was utilized to visualize the networks at selected intervals.

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