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Academic organizations and new industrial fields: Berkeley and Stanford after the rise of biotechnology

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ABSTRACT

The increasing intertwining of academic and commercial research networks has led to fundamental changes in the organization of modern science. Industry links not only affect the professional dynamics within individual scholarly communities but also affect the position of these communities in their broader academic environment. This paper outlines how industry ties open up opportunities for scientific institution builders to strengthen the legitimacy of their fields of scientific enquiry within this environment. How an academic environment shapes efforts by institution-builders to pursue these opportunities is examined in the context of reorganizations in the life sciences at the University of California at Berkeley and Stanford University following the rise of biotechnology during the 1980s and 1990s. This study also highlights how different models of technology transfer shaped the organizational structures of the expansionist initiatives pushed through at these two universities by molecular biologists with close industry ties.

1. Introduction

The world of commerce has gained an ever stronger foothold on American university campuses over the last decades (e.g. Gibbons et al., 1994; Etzkowitz and Leydesdorff, 1998; Slaughter and Leslie, 1997). As studies of key scientific fields such as the life sciences highlight, firms have now become an integral part of scholarly networks within which the creation of scientific knowledge is organized (e.g. Kenney, 1986; Liebeskind et al., 1996; Owen-Smith and Powell, 2004; Owen-Smith et al., 2002). The increasingly strong links between university laboratories and firms have had far-reaching consequences for the institutional landscape in which academic scholars operate.

Apart from altering the day-to-day professional lives of scientists, industry links have had important implications for relationships among scholarly communities within universities. Academic scholarship in modern science is organized in a social order, in which different scholarly communities (e.g. research groups, departments) vie for legitimacy. This study will highlight that the rise of a new science-based industrial field constitutes a disruptive event that provides opportunities for academic institution builders to reshape this social order in their favor. Moreover, this study will examine the mechanisms through which the broader organizational environment, in which a scholarly community is embedded, affects the strategies these institution builders use to pursue the opportunities offered by the rise of new science-based industries.

In no field have the altered dynamics governing the production of scientific knowledge been more apparent than in the biomedical fields opened up by the rise of biotechnology. Fuelling advances in some of the most notable scientific areas to emerge over the last decades such as genome sequencing, stem cell research and molecular medicine, molecular biologists with their close industry ties to biotechnology have been very successful in attracting support for their scientific programs. Over the last decades, many of the most significant infrastructure investments at American university campuses have been

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investments in molecular biology. Moreover, initiatives by scientific institution builders in molecular biology have been matched by major increases in funding support for the biomedical sciences. For example, congressional appropriations for the National Institutes of Health alone (the key funding agency for basic biomedical research) increased from USD 2.1 Billion in 1975 to USD 29.5 Billion in 2008 (National Institutes of Health, 2008).

In order to better understand the processes that shaped expansions in molecular biology, this study develops a framework to analyze organizational changes at universities. Within this framework scholarly communities in science are seen as socially embedded and organizational outcomes as shaped by struggles over legitimacy among different communities. Zooming in on initiatives led by scholars from two small groups of molecular biologists with close industry ties at the biochemistry departments of the University of California at Berkeley (Berkeley) and Stanford University (Stanford), this study analyzes how these scholars reshaped the local social order governing the life sciences within their universities following the rise of biotechnology.[1]

Before the birth of biotechnology, the pursuit of scientific knowledge in various academic communities in biology at Berkeley and Stanford was fragmented. In this environment, molecular biologists tied to these universities' biochemistry departments, like most other scholarly communities in the biological sciences, were organized around a distinctive, separate scientific program. During the 1960s and 1970s, molecular biologists on both campuses attempted on several occasions to mobilize support around expansionist initiatives that encroached on the scientific territories of other scholarly communities in biology. These initiatives, however, were repeatedly thwarted.

All changed after the advent of biotechnology. The altered frames used to legitimize their scholarly activities allowed molecular biologists within the organizational environment at Berkeley and Stanford to attract support for a number of major, expansionist initiatives. These initiatives significantly extended the control by molecular biologists over scholarly resources on their campuses.

This paper is structured as follows. First, it outlines a framework for conceptualizing processes of organizational adaptation by universities following the rise of new science-based industrial fields. Second, it puts into its historical context, the role played by molecular biologists from Berkeley's and Stanford's biochemistry departments in the emergence of the biotechnology industry in the San Francisco region and discusses why major initiatives led by members of this group constitute an interesting case study. Third, it presents a number of new empirical findings. Fourth, it assesses these findings through the lens of the proposed theoretical framework. Finally, it identifies avenues for further investigation.

2. Theoretical framework

Understanding how scientific knowledge advances requires an examination of how academic actors establish legitimacy in their social environment. Over the last decades scholarship in the sociology of science has changed its emphasis on what it considers the key institutional rules and norms that determine strategies open to scholars to advance their standing. Pioneers in the sociology of science such as Merton (1979) and Ben-David (1991) view the accumulation and transmission of knowledge within the scientific profession as governed by a set of universal rules and norms. Contemporary scholars, however, have moved away from this conception of science and have embraced one that views the pursuit of knowledge in science as organizationally dis-unified. As a result, scholars have shifted their focus towards uncovering the mechanisms through which local social orders shape what and how scientists know. New institutional theories, which view social action as determined by structures of 'fields' (Bourdieu, 1977; DiMaggio and Powell, 1983) or 'games' (Axelrod, 1994) have been instrumental in supporting this shift.

Within a conception of science as organized in a range of distinctive communities, efforts by scholars to advance their standing are determined by their social environment at different organizational levels. Firstly, scientists' actions are constrained by the social rules and norms of the particular scholarly community they are a part of (e.g. department, discipline, laboratory). Scholars have gained important insights into the organizational processes through which scientific 'facts' are constructed within laboratories (e.g. Hacking, 1996; Galison, 1987; Latour and Woolgar, 1979; Latour, 1987). Moreover, sociologists of knowledge highlight the importance of so-called local 'epistemic cultures' that provide structure to these processes (Knorr-Cetina, 1999). In addition, sociologists link the organization of these local 'epistemic cultures' to the organization of more extended social networks or 'invisible colleges' (Crane, 1968, 1972) that group together the activities of different local communities within academic disciplines.

Most of the existing scholarship dealing with the impact of intensifying science–industry relationships on academic institutions fits in this tradition and focuses on how structures of individual scholarly communities changed in academic settings where industry ties became a key social connection shaping scientists' professional lives. Studies highlight how increased secrecy and 'proprietarism' associated with the world of commerce conflict with the so-called Mertonian system of norms, which is associated with the open science model of research (Blumenthal et al., 1997; Campbell et al., 2002; David, 2003; Eisenberg

[1] This paper, which focuses on the development of the biological sciences during the 1980s and 1990s, uses the term molecular biology to denote all scientific research that relies on the "language of DNA" to explain and control biological processes. Some scholars, mostly in studies of the early, formative stages of the history of molecular biology, have used the term molecular biology more narrowly to describe only one of the three separate research fields (the other two being genetics and biochemistry), in which pioneering research on the genetic underpinnings of biological processes was carried out. However, during the 1960s and 1970s, following the discovery of new genetic engineering techniques, these three fields converged and scientists from these previously separate fields found a common scientific language (e.g. Morange, 1998b).

and Nelson, 2002; Heller and Eisenberg, 1998; Murray and Stern, 2005). The processes through which scientists resolved this conflict and reconciled institutional rationales governing academic and commercial work within the context of individual scholarly communities are documented in a number of recent studies. These studies examine changes within individual scholarly communities in the research leads scientists pursue in their work (Kleinman, 2003), in the way scientists define their professional identities (Owen-Smith and Powell, 2001; Smith-Doerr, 2004, 2005) and in the role scientists attribute to patenting in the scholarly process (Colyvas, 2007).

Although professional rules and norms governing individual scholarly communities play an important role in accounting for the construction of knowledge in modern science, the activities carried out within these communities are legitimized in a broader organizational environment. This paper proposes that in order to understand how universities adapt when members of a particular scholarly community forge links to industry, it is necessary to examine how these links empower or constrain members of this community to strengthen claims of legitimacy relative to claims by members of other communities within the social context of a specific university.

Organizations tie together activities of multiple groups that often have conflicting interests and the structures of organizations reflect power relationships among these groups (e.g. Collins, 1981). These structures tend to be self-reinforcing most of the time and constrain efforts by challengers that aim to disrupt the existing order. During periods of crisis, however, when key premises underlying existing orders become contested, the position of incumbent groups becomes more vulnerable and opportunities arise for institution-builders to redefine social orders and advance their interests (Fligstein and McAdam, 1995). The challenges these institution-builders face have also been likened to the challenges leaders of 'social movements' face (Fligstein, 1996; McAdam and Scott, 2005). Understanding organizational structures therefore requires understanding the social environment, on which members of different groups relied in struggles for legitimacy during periods of field (trans)formation.

This study views the adaptation of university organizations following the rise of new science-driven industrial fields through the lens of these theories of field (trans)formation. Potential contributions to technological innovation have been a key source of legitimacy throughout the history of modern science. Therefore, the success of one scholarly community over another scholarly community in linking its scientific activities to innovation in a new technological field is seen as a disruptive event that opens up opportunities to challenge the existing 'balance of power' within the local social order of a university.

The proposed focus on struggles for legitimacy among scholarly communities to analyze processes of organizational change within universities requires a broader conceptual framework, which encompasses an institutional environment that extends beyond individual scholarly communities. Table 1 highlights how this framework is distinguished from the framework underlying the existing literature on science–industry relationships.

Within the proposed framework control over organizational resources by members of different scholarly communities is not seen as a given but is considered a key source of contention. This premise differs from the premise underlying our current understanding of the dynamics shaping science–industry relationships. Whereas for sociologists of science such as Ben-David and Merton, who view the pursuit of knowledge in science as universal, there is no hierarchy among scientific programs, most contemporary scholarship in sociology of science is more concerned with highlighting the organizational dis-unities in science than with the interdependencies among activities of scholarly communities. Relative rankings of legitimacy, which form the basis for the allocation of resources within academic organizations, have therefore not been a key concern in both these traditions.

The proposed framework, moreover, views the group of actors shaping the organization of scholarship in modern science as a more encompassing group. Examining episodes of disruptive changes in the history of science, historians such as Lenoir (1997) and Biagioli (1993) emphasize the importance of actors such as patrons that are external to university organizations in shaping the scientific endeavor. These scholars link the success of institution-builders in gaining legitimacy to their ability to define research agendas within cultural frames that appeal to the interests of actors outside their group of direct scientific peers. Because of this importance of external actors in the establishment of legitimacy of scientific programs, these actors need to be seen as integral to the processes shaping knowledge in modern science.

Finally, struggles for legitimacy among scholarly communities within universities are shaped by the broader social environment, in which these communities are

Table 1
Science as shaped by the organization of specialized professional communities vs. science as shaped by competing 'social movements'

	Professional communities view	Social movements view
Examined outcomes	Knowledge production or academic practices within a given scholarly community	Position of scholarly community in local order as the subject of contention
Relevant actors	Importance of peers within community in establishment of legitimacy	Central role of actors external to community (e.g. patrons, administrators) in establishing legitimacy
Level of analysis	Production of knowledge as shaped by rules, norms of individual professional community (e.g. department, laboratory, discipline)	Production of knowledge as shaped by broader social, cultural environment, in which scholarly community is embedded

embedded. Departing from Robert Merton's view that science is organized in autonomous scholarly communities, recent historical studies bring to light links between organizational structures governing scholarly enquiry and the specific social and cultural environment in which these structures take shape. In particular, linking their scholarship to the existing new institutional literature on organizations (DiMaggio and Powell, 1983), these studies emphasize how institution builders devise organizational strategies, which incorporate existing social rules and norms governing their external environment. Drawing on these insights, sociologists of knowledge have turned their attention to differences in national 'academic cultures' or 'intellectual traditions' (Fourcade-Gourinchas, 2001; Ringer, 1992; Swidler and Arditi, 1994). These differences are linked to the organization of national political–cultural fields within which scientists established new scholarly fields.

Having outlined the key premises of the proposed framework, it is now possible to articulate in more detail how organizational changes within universities following the rise of new science-based industrial fields are linked to the broader social, cultural environment in which these changes take shape. Institution builders in new scholarly fields linked to industry need to deal with two key challenges in relating to actors outside their individual scholarly community in order to prevail in struggles for legitimacy.

Challenge 1; Co-opt other groups within university to support expansion

A first key challenge for institution builders aiming to harness the rise of novel science-based fields is to convince others within their university of the importance of their scientific programs. Institution builders must forge alliances with key decision-makers and countervail opposition of competing groups against their expansionist initiatives. This requires institution builders to reconcile the organizational framing of their initiatives with the accounts used within the university to legitimize the university's scholarly mission and its relationship to the outside world. These pre-existing institutional models governing scholarly enquiry within a university thus are an important driver of processes of organizational adaptation following the rise of new science-based industrial fields.

Challenge 2; Co-opt groups outside the university to support expansion

A second key challenge for scientific leaders seeking to enhance the standing of their scientific programs is to attract support from actors outside the university. As has been highlighted, cultural narratives that define the relationship between a university and its external environment play an important role in the organizational development of universities. Scholarly communities are required to link organizational frames they use to legitimize their activities into these narratives in a way that appeals to external actors such as patrons. Moreover, the success of expansionist initiatives by institution-builders is closely linked to their ability to establish such links more convincingly than members of other communities.

3. Research design

The empirical sections will examine the dynamics through which organizational models governing academic scholarship at Berkeley and Stanford and frames defining the relationships of these universities to their external environment shaped expansionist initiatives by molecular biologists from these universities' biochemistry departments following the rise of biotechnology during the late-1970s and 1980s.

The 1970s formed a turning point in the history of molecular biology that heralded the dawn of an era in which scholarly enquiry in molecular biology became closely linked to industrial innovation. The period from the end of the Second World War until the 1970s was one of major discoveries, which provided the central conceptual building blocks for the discipline (Bud, 1993; Judson, 1996; Morange, 1998a). The discovery of new genetic engineering techniques during the early-1970s, which allowed biologists to move from describing molecular mechanisms governing biological processes to explaining and controlling these mechanisms, would radically alter the field (Morange, 1998b). Whereas previously the empirical focus of scholarly enquiry was on biological processes in simpler organisms, the discovery of new genetic engineering techniques would open up novel scientific opportunities in the context of more complex organisms such as humans.

Advances made in the field during the 1970s empowered molecular biologists to frame their field as one that had significantly gained in industrial and technological value relative to other fields in the biological sciences. Scholarly life in molecular biology, like scholarly life in other fields in the biological sciences was detached from technological concerns in industry during the 1950s and 1960s. This changed from the late-1970s following the formation of the biotechnology industry around scholarship in molecular biology.[2] The growth of the biotechnology industry during the late-1970s and 1980s was concentrated in a limited number of regions in the United States housing academic 'star scientists' in molecular biology (Zucker et al., 1998); the San Francisco Bay Area was the most prominent of these regions (e.g. Kenney, 1986).

Molecular biologists at the biochemistry departments of Berkeley and Stanford played key roles in this transformative period of their discipline. Both departments were ranked among the top-three departments in their field in both the 1969 and 1982 rankings of graduate programs in the United States and important scientific discoveries in the field of genetic engineering were made at these departments (Jones et al., 1982; Roose and Andersen, 1970). Moreover, scholars at the biochemistry departments of

[2] An extensive literature exists detailing the impact of biotechnology on the industrial dynamics in agriculture and the pharmaceutical sector (e.g. Hall, 1987; Kenney, 1986; Kloppenburg, 1988; McKelvey, 1996; Rabinow, 1996).

Berkeley and Stanford involved in genetic engineering research made important contributions to the development of the biotechnology industry in San Francisco early on in its development.

Although Berkeley and Stanford were universities of similar high scientific esteem, the academic traditions guiding scholarly life at these two universities were different in important respects, in particular in relationship to industry. Economists and sociologists of science have highlighted as a unique distinguishing characteristic of the 20th century American university its emphasis on industrial relevance in research and training (Ben-David, 1977; Geiger, 2004; Rosenberg and Nelson, 1994). Berkeley and Stanford did not diverge from this characterization. At both universities, contributions to the public welfare in general and technological innovation in particular were key elements in the general legitimating accounts that defined the relationship between these universities and their external environment (e.g. Kerr, 2003 on Berkeley; Gillmore, 2004; Lowen, 1997 on Stanford). However, Berkeley and Stanford significantly differed in the way industry fitted into organizational models governing their scholarly activities.

The rise of Stanford as a leading American research university has been connected to a model of academic scholarship in which local technical communities play an integral role. These historically included both communities in industry as well as outside industry (e.g. defense, medicine). Over the years senior scientists and administrators at Stanford developed a number of organizational innovations governing the interface between science and industry. These innovations linked up and leveraged relationships with technical communities as a way to advance scholarship in new fields of scientific enquiry. Not only did new ways of organizing the interface between science and industry secure to Stanford a place at the forefront of American science, they also explain the role the university played in fuelling innovation in Silicon Valley high-tech industries. Organizational innovations pioneered at Stanford include the modern patenting and licensing office, the science park and the industrial affiliates program (Gillmore, 2004; Kenney, 2000; Mowery et al., 2004; Saxenian, 1994). A study on the role of patenting in research practices in the biomedical sciences at Stanford highlights that by the 1980s this model of technology transfer also had permeated through the university's life sciences organization (Colyvas, 2007).

In contrast, Berkeley's organizational model kept industry at arm's-length. As the pinnacle of the Californian public system of higher education, Berkeley relied on the state for major infrastructure investments during most of its post-Second World War history. The academic standing of the university was seen as of key economic and industrial importance by the state. However, unlike at Stanford, at Berkeley the development of close links to technical communities outside the realm of science was generally not seen as integral to strengthening this academic standing. Berkeley's arm's-length relationship can be linked to a more traditional 'linear' view of the innovation process, in which academic and practitioner communities play complementary but separate roles that do not need to be integrated. For example, Berkeley severed its ties to the University of California's medical school in San Francisco (currently the University of California at San Francisco) during the 1950s when preclinical research and teaching in anatomy, biochemistry, and physiology were moved to San Francisco. This allowed Berkeley to concentrate on its basic research activities in the biological sciences.[3] A recent study by Kenney and Goe (2004) of the electrical engineering and computer science faculties at Berkeley and Stanford found a lower level of embeddedness of Berkeley's faculty in industry networks. Finally, Berkeley's approach to technology transfer has traditionally been more hands off. For example, unlike Stanford, Berkeley did not have an on-site patenting and licensing office until 1990; before 1990 patenting and licensing decisions were made from a system-wide technology transfer office for all campuses of the University of California in Oakland (Mowery et al., 2004).

The following sections will analyze how efforts by members of Berkeley's and Stanford's biochemistry departments to benefit of the technological, industrial relevance their scientific programs had gained through the lens of the different institutional environments at these two universities. The historical account that is constructed relies on archival research, interviews and citation counts from the Web of Science SCI database. The oral histories used in this study consist of a set of oral histories gathered by Berkeley's Regional Oral History Office with industry pioneers and important molecular biologists from Berkeley and Stanford and additional interviews conducted by the author himself. This study also relies on documents collected from the Archives and Special Collections Sections of the Bancroft Library at Berkeley and the Green Library at Stanford that deal with the history of biology at Berkeley and Stanford.[4]

4. Reorganizations at Berkeley and Stanford

Before the 1980s and 1990s, molecular biologists from Berkeley's and Stanford's biochemistry departments had attempted on several occasions to attract support for initiatives that aimed to expand networks of expertise and skills they could rely on in their research. These efforts mostly ended in failure. For example, molecular biologists in partnership with the university administration at Stanford tried to put Paul Berg of the biochemistry department in charge of the university's largest biology department, the Department of Biological Sciences, in the 1960s (Lowen, 1997). This proposal was widely seen as an attempt to shift the scholarly focus of the Department of Biological Sciences towards a field favored by molecular biologists of the biochemistry department. As a result, the proposal encountered strong resistance from scholars with

[3] 'UCSF 1864–1989: 125 Years of Excellence,' document available for consultation in the Special Collections and Archives section of the Kalmanovitz Library of the University of California at San Francisco.

[4] Documents from these libraries used in this study are mainly departmental and administrative records and personal papers of retired faculty members, which often also contain documentation on the involvement of these faculty members in firms.

vested interests in other fields of enquiry and eventually failed.[5]

Similarly, a group of molecular biologists attempted to create a new department of "general biology" at Berkeley in 1962, in which all research on molecular mechanisms governing living organisms on campus was to be united.[6] This initiative too encountered resistance by other biologists who felt that this plan encroached on their 'scientific territories'. In the end, the initiative was organized inside a new Department of Molecular Biology, separate from existing departments, which were left intact.

4.1. The University of California at Berkeley

The scholarly community of Berkeley's biochemistry department was organized mostly in isolation from other scholarly communities on campus during the 1970s. Different scholarly communities in biology had confined themselves to their departments and had become increasingly isolated from each other over the course of the 1950s and 1960s (Jong, 2006). As highlighted, numerous failed attempts had been made to remedy the situation and to bring together scholarly activities in related areas. Only after the rise of biotechnology would a group of biologists succeed in breaking down the barriers that had existed between various disciplinary communities.

Berkeley's biochemistry department was older and larger than Stanford's. It had been founded in 1948 and counted 17 principal investigators in 1978.[7] Moreover, the department was more diverse in terms of its scholarly focus than Stanford's biochemistry department and not all investigators at the end of the 1970s were involved in research that could be directly tied to the emerging biotechnology field. However, a number of faculty members that was involved in genetic engineering research developed close industry ties, very early on in the development of the biotechnology field. Although molecular biologists at Berkeley's biochemistry department mostly continued to refrain from patenting during the 1980s they did become involved in the nascent biotechnology industry as consultants and as founders of firms.[8] Most notably, Edward Penhoet left the biochemistry department to lead Chiron, which he had co-founded in 1981 with Pablo Valenzuela and his former supervisor Bill Rutter of the University of California at San Francisco. Robert Tjian would play an important role on the scientific advisory board of Genentech during the 1980s, before founding his own biotechnology firm Tularik with David Goeddel and Steve McKnight.

The fragmentation of scholarly resources across a wide range of departments was increasingly seen as an obstacle for molecular biologists involved in genetic engineering to maintain their scholarly standing. Pursuing new scientific avenues opened up by the discovery of genetic engineering techniques required a broader base of specialized research and training expertise than was available at the time within the biochemistry department. In order to remedy the organizational fragmentation in biology, towards the end of the 1970s molecular biologists with close industry ties working in the field of genetic engineering started to lobby the university administration to unify Berkeley's fragmented scholarly communities in the biological sciences behind their agenda. These lobbying efforts gathered momentum following the rise of biotechnology and members of the biochemistry department managed through a series of major initiatives to expand their control over scholarly resources on campus, inside and later also outside the biological sciences.

At the urging of molecular biologists, Roderick Park, the University Provost instated the Chancellor's Advisory Committee on Biology (CACB) in 1980 to review the state of biology at Berkeley and he appointed Daniel Koshland to head this committee (Koshland, 2003). Koshland would become the key institution-builder in the biological sciences at Berkeley during the 1980s. As a leading molecular biologist, Koshland was a former chair of the biochemistry department and chief editor of Science Magazine. Moreover, Koshland was one of Berkeley's earliest and most vocal biologists to embrace the biotechnology industry. In fact, he was already extolling the importance of the biotechnology industry for the future of Berke-

[5] The following fragment from a letter dated June 26, 1965 addressed to President Sterling, by a senior member of the Department of Biological Sciences, George Myers with the subject heading 'ad hoc committee for the re-examination of biology at Stanford' reflects the view among members of the biological sciences department about this committee. Myers wrote;

> "I think none of my colleagues in the Department of Biological Sciences would disagree with my opinion that no good department should fear reappraisal, if made by men they believe to represent broad and deep enough competence and understanding. However, your committee of reappraisal is heavily weighted on the biomedical, biomolecular, biochemical side (Djerassi, Lederberg, Yanofski, Glaser, Kornberg and possibly even Phillips) with only two relatively junior men (Kennedy, Holm) to represent a spectrum of biology far wider than that represented by the majority. This, and the working of your directive, is regarded by me'.... 'as protending a future shift towards the restriction of Stanford biology to what has been called the molecular or biochemical side."

Source: Terman papers, available for consultation from the Stanford University Archives.

[6] See report of 'The committee to plan the scope and activities of a new department concerned with relating biology and the physical sciences,' available for consultation from Wendell Stanley papers at the Bancroft Library, University of California at Berkeley.

[7] See Creager (1996) and Jong (2006) for more on the early history of the department. 1978 faculty count from booklet 'Department of Biochemistry, University of California at Berkeley; Information for graduate students, 1978,' obtained from the administration of the Department of Molecular and Cell Biology at Berkeley.

[8] An online search through the United States Patent and Trademark Office shows only two patents that were filed during the 1980s that listed inventors who were also listed as on the faculty of Berkeley's biochemistry department in 1981. The two faculty members that were listed as inventors on a patent were Frederick H. Carpenter and Giovanna Ferro-Luzzi Ames. List of faculty members obtained from booklet 'University of California at Berkeley; Graduate studies in biochemistry, September 1981,' obtained from the administration of the Department of Molecular and Cell Biology at Berkeley.

ley when the industry was still highly controversial on campus.[9]

The reports put forward by the CACB during the early 1980s started out with the premise that laying the scientific foundations for new biotechnology innovations and training scholars for industry research positions should be central objectives around which to organize Berkeley's future.[10] These reports also embraced the view that the fragmentation of biology across disparate scholarly communities was a crucial obstacle to achieving these objectives. Reports produced by an external review committee, which was instated to validate assessments and recommendations made by Koshland's committee, supported the committee's claims (External Review Committee, 1981, 1986).

In order to strengthen Berkeley's position in new genetic engineering fields the CACB pushed through two sweeping changes in the organization of biology. First, faculty recruitment in biology at Berkeley was centralized and Koshland's committee requested and was granted control over the composition of faculty search committees during the early 1980s (Koshland, 2003, p. 7). The centralization of decisions regarding faculty recruitment provided a powerful tool that Koshland's committee was able to use to focus scholarly resources in its preferred scientific fields.

Second, Koshland's committee oversaw a departmental realignment in the biological sciences that included the closure of Berkeley's 10 main biology departments, housing around 150 faculty members, and the transfer of these faculty members into two new departments (see Table 2). This realignment was completed in 1989. One of the two new departments that was foreseen in the reorganization plans was a new, inter-disciplinarily organized, 'mega' Department of Molecular and Cell Biology with around 90 faculty members. The core of this new department would consist of faculty members of the old Departments of Biochemistry, Genetics and Molecular Biology. In this new department, Koshland's committee envisioned the creation of a multidisciplinary community where Berkeley's molecularly oriented biologists would be better equipped to extend the reach of research and training programs to the study of more complex organisms and focus on therapeutically relevant topics.

Table 2
Biology departments in Berkeley's College of Letters and Sciences before and after 1989 reorganization in the life sciences

Before	After
Biology	Integrative biology
Biostatistics	Molecular and cell biology
Botany	
Paleontology	
Zoology	
Bacteriology and immunology	
Biochemistry	
Medical physics	
Molecular biology	
Neurobiology	
Physiology–anatomy	

Source: Document of Bioscience Staff Planning Office, dated September 19, 1988, from binder on reorganization of biological sciences at Berkeley, available on request at Bancroft Library, University of California at Berkeley.

Key to the success of efforts by molecular biologists to focus resources in new fields of scientific enquiry was their embrace by university administrators. These university administrators saw these efforts as an opportunity to attract support for the university from external patrons, most notably the state of California. The 1970s and early 1980s were a period of significant fiscal constraint in California during which the state withheld funds for major capital investments on the Berkeley campus. The rise of a new industry closely tied to scholarly enquiry that was perceived as of great importance to the Californian economy offered the opportunity for university administrators to lobby the state legislature for major infrastructure investments. Seeking to capitalize on this opportunity, university administrators made investments in new scholarly fields aligned with the biotechnology industry the centerpiece of an effort to attract state funding.[11] In the end, the state legislature agreed to commit itself to providing funding for the capital investments detailed in Koshland's plan on the condition that the university attract one third of the required investments from private donors. This led administrators to organize Berkeley's first major private fund-raising campaign (Park, 2003).

Moreover, the promise of possible spillovers of funding support to other scholarly communities, from the support molecular biologists and university administrators were

[9] Koshland's early strong endorsement of biotechnology becomes for example clear from a letter by Koshland to William G. Hollimann, dated August 21, 1981, in which Koshland expresses his strong support for a state initiative to build up a science park for biotechnology firms near Berkeley: 'As a Professor at Berkeley, I am convinced that our program in the biological sciences would be helped immeasurably by a thriving biotechnology industry nearby.' William J. Rutter papers, available for consultation in the Special Collections and Archives section of the Kalmanovitz Library of the University of California at San Francisco. Moreover, looking back on the way he made a case for increased funding for molecular biology during the 1980s Koshland highlights how his committee and university administrators were successful during this period in reframing the research agenda of molecular biologists, who until the formation of the biotechnology industry had mostly isolated themselves from practical concerns and industry, as a research agenda of key practical importance (Koshland, 2003, p. 27):

> 'I think we made a good case. I think biology is easier to sell in the modern era than, let's say, physics. Physics was easy to sell after the atomic bomb. You had to have physicists around to keep ahead; otherwise, other nations would get ahead. The Russians were now getting the bomb, and they weren't very friendly. The same is true nowadays for biology. It was pretty obvious that health and disease were becoming very big factors in the life of everybody, and therefore biology was a pretty good sell. It's even more in the headlines now.'

[10] See 'Final report, Internal Biology Review Committee, 1981,' 'Final report; reorganization of the life sciences, CACB, 1986,' and 'The biological sciences, External Review Committee, 1981,' all available from the binder on the reorganization of the biological sciences at Berkeley, Bancroft Library.

[11] In a key speech Berkeley Chancellor Ira Michael Heyman held at the California State Legislature to obtain state funding for the reorganization of the biological sciences. Heyman for example almost exclusively focused on the human health benefits and the trained industry scientists, support for Berkeley's initiative in the biological sciences would result in (draft for speech to legislature, dated March 31, 1982, from binder on the biological sciences, available for consultation in Berkeley's Bancroft Library).

able to attract from outside patrons, was key to the success of the initiatives promoted by molecular biologists. Administrators were careful to include smaller needs into their fund-raising campaign that did not sound 'sexy' to outside patrons (Park, 2003, p. 62). As a result, also scholarly communities outside the group of molecular biologists that were the driving force behind the organizational realignments in the biological sciences gained an interest in the success of these plans.

Koshland's drive to focus scholarly resources in new biomedical fields opened up by the rise of biotechnology in many respects achieved its objectives. Berkeley was the first major research university without a medical school to obtain support for the creation of a Howard Hughes Medical Institute on campus when Gerald Rubin and Robert Tjian were appointed Howard Hughes Investigators in 1987 (Koshland, 2003). Moreover, Berkeley's overhaul of the biological sciences formed a model used by other major research universities realigning their organizations in the biological sciences such as the Universities of Wisconsin, Illinois and Texas, and the California Institute of Technology (Taylor, 2003; Trow, 1999).

Like previous initiatives emanating from the group of molecular biologists at Berkeley to expand control over scholarly resources on campus during the 1950s and 1960s, the initiatives led by Koshland proved controversial. Resistance was strong against the outlined organizational realignments by scientists in fields such as population biology and ecology, who did not share an interest in the new fields that were fuelling innovation in biotechnology. The plans, which included the closure of a range of departments were at the time seen as 'devastating to parts of the biology community' (Taylor, 2003, p. 88). Moreover, although Koshland's proposals constituted a plan for the whole biology community at Berkeley, initial members of the CACB were mainly molecular biologists and the first proposals coming out of the CACB favored their interests. The rise of the biotechnology industry was an important factor that allowed molecular biologists to prevail in ensuing struggles for legitimacy with other scholarly communities in biology during the 1980s for a number of reasons.

Firstly, Berkeley's position in scientific fields opened up by the rise of biotechnology was increasingly seen as problematic for the whole of the university.[12] During the 1970s and 1980s universities such as the University of California at San Francisco and the Massachusetts Institute of Technology rose to prominence, which had built up more focused, integrated research and training programs around the biomedical fields that had been opened up by the rise of biotechnology. It was in this environment that contributions to biotechnology consolidated as a key determinant of the standing of major American universities in biology and Berkeley's pluralistic organization increasingly faced pressures to narrow down its scientific focus.[13]

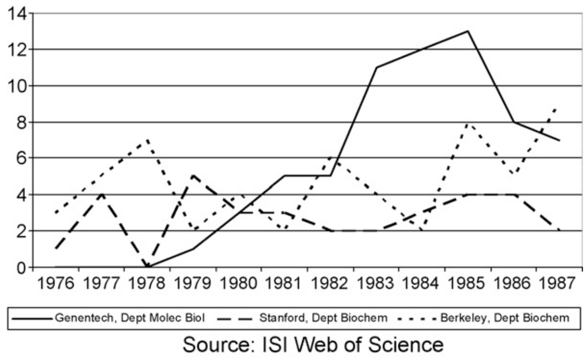

Fig. 1. No. of Science and Nature publications Biochemistry Departments of Berkeley and Stanford, and Molecular Biology Department of Genentech.

Second, Koshland's plans gained urgency not only because of competitive pressures by other universities, but also because of the rise of the local biotechnology industry as a force to be reckoned with in struggles for academic esteem. Difficulties Berkeley's laboratories experienced in competing with less-established commercial laboratories of nearby biotechnology firms in important new scientific fields were especially seen as an embarrassment. As Fig. 1 shows, during the period from 1981 until 1986 with the exception of 1982, scientists of the Department of Molecular Biology at Genentech published more articles in Science and Nature, two of the most prestigious scientific journals, than their more numerous counterparts at the biochemistry departments of Berkeley and Stanford, who worked on related and in many cases similar research problems. These difficulties provided a powerful argument for change for scientists around Koshland who during this same period promoted initiatives that were focused on research areas of relevance to biotechnology.[14]

[12] Concerns for the standing of Berkeley's biological research departments in national rankings is one of the recurrent arguments used to justify the major investments in the biological sciences at Berkeley during the 1980s. See for example, Trow (1999) and various documents produced for the public by the university to support fund raising activities associated with Berkeley's reorganization during the 1980s, available for consultation at Berkeley's Bancroft Library from a binder on the reorganization of the biological sciences at Berkeley.

[13] During the early 1980s, Berkeley's research organization of the biological sciences was considered to be among the most pluralistic in the United States. Koshland (2003, p. 2) for example comments on the presence of several departments covering more traditional research fields, which were increasingly standing out as follows:

> 'the zoology department was considered one of the best in the country. But, as it turned out, it was the only zoology department in the country . . ..'

[14] See for example remarks made by Edward Penhoet (2001, p. 110), an Assistant Professor of Biochemistry at Berkeley at the time of the formation of the first biotechnology firms, about how the inability of Berkeley scientists to out-publish scientists of the new biotechnology firm Genentech during the early 1980s created a momentum for change for those on campus who sought to undertake major institutional initiatives designed to promote more industrially relevant molecular biology research on the Berkeley campus;

> '. . . the reason this campus reinvested in biology [the reorganization of biology at Berkeley in the 1980s] was because Genentech was publishing more papers than the whole UC Berkeley campus in the biological sciences. So there was no question it had a big impact.'

Third, the biotechnology industry in the San Francisco region was increasingly having an impact on requirements for graduate training and the ability of Berkeley to attract the best graduate students. Up to the mid-1970s, graduates of Berkeley's graduate programs in biology practically never moved to industry positions and graduate training was focused on preparing students for academic careers. However, the formation and rapid growth of the biotechnology industry created a strong industrial demand for molecular biologists with training in using new genetic engineering techniques to study clinically relevant research problems. The proportion of graduate students and postdoctoral students moving into industry positions grew from practically zero during the mid-1970s to around one-third at the beginning of the 21st century.[15] This was seen as necessitating a reassessment of the organization of graduate programs in biology at Berkeley.

Following the completion of the reorganization of the biological sciences at Berkeley during the 1980s, Koshland resigned as chair of the CACB and was succeeded by Robert Tjian in 1992. Tjian, who like Koshland had been a member of the biochemistry department until it was abolished in 1989, was among Berkeley's most renowned scholars in molecular biology. Moreover, Tjian had a strong track record in the local biotechnology industry. Building on the reorganizations initiated by Koshland's committee during the 1980s, Tjian developed a new set of ambitious initiatives aimed at positioning Berkeley as a key driver of innovation in biotechnology. The Health Sciences Initiative, which had a USD 500 Million budget, became the most important of these initiatives. Tjian (2004) reflected on the relationship between the Health Sciences Initiative and his experiences in the biotechnology industry, first at Genentech as a member of the scientific advisory board and later as a co-founder of one of the San Francisco region's most successful biotechnology firms, Tularik:

> 'How has being on the scientific boards of companies influenced my research? Well, it hasn't influenced my research, particularly at the ground level. What it has done is that it has very much influenced the way I think science should be done on a bigger scale. So it very much influenced the Health Sciences Initiative.
>
> So what is the Health Sciences Initiative? Part of it is what I saw when I was at Tularik where I have been over the past thirteen years. You now know that Tularik's main goal is to make small molecules; that means chemistry. And yet those small molecules have to be screened using the most sophisticated biology. So that meant that I had to have a group of biologists that were the best; I had to have a group of chemists that had to be the best; I had to have a group of bioinformatics people that were the best; People who were engineers to develop the robots to do the high throughput screening. So basically, at Tularik during a very small time period I had to develop expertise in all of these areas. And then I realized that not only you have to develop the expertise; you have to hire the right kind of people, and then those people have to talk to each other.
>
> Those are all the same things that I am trying to achieve in the Health Sciences Initiative at Berkeley but at a much bigger scale. Because we got biologists on campus, we got chemists on campus, we got biophysicists on campus, we got bioengineers, we got computational people. At Tularik all those people work together, working on the same project; At Berkeley there is not that motivation and so we are loosing a lot of opportunities to use interdisciplinary information to move the science forward because there is no overriding system. Because at Tularik it was clear; chemists had to talk to biologists, otherwise you weren't going to get to the product, right. Here there is not that kind of motivation, but there should be.
>
> And so my vision of the Health Sciences Initiative is a slightly changed emphasis on the campus. Traditionally at Berkeley you hired a good scientist, they were left alone, they did their own thing and maybe they never talked to anybody else. But we would really like to see much more collaboration at every level, from the graduate students in one lab talking to another one, all the way up to faculty. And that is really the goal.'

It is clear from the design (and title) of the *Health* Sciences initiative that the 'overriding system' Tjian mentioned was primarily oriented towards topics of relevance in the context of biotechnology. The aim of the Health Sciences Initiative was thus to further extend networks of expertise and skills at Berkeley, required to move forward the new scientific programs opened up by the rise of biotechnology. Like the reorganization led by Koshland during the 1980s, the Health Sciences initiative spearheaded by Tjian broke down existing barriers and integrated scholarly activities of a wide range of disciplinary communities that up until the mid-1980s had been mostly organized independently from each other. However, whereas reorganizations during the 1980s were limited to bringing into line research activities of scientists in biological research disciplines, the Health Sciences Initiative also aimed to integrate research outside the biological sciences into the scholarly programs opened up by the rise of biotechnology.

Crucial for the Health Sciences Initiative has been the creation of two new facilities, namely the Li Ka Shing Center for Biomedical and Health Sciences and the new Stanley Biosciences and Bioengineering facility. These two new facilities are planned to house research activities involving not only biologists, but also physicists, engineers, mathematicians, computer scientists and chemists, all collaborating on research problems that had previously primarily been the domain of molecular biologists on the Berkeley campus.

Thus, under the leadership of a small group of molecular biologists from the biochemistry department with close industry ties, Berkeley's research organization in biology underwent a radical transformation in a period of around 20 years. From being a university in which various disciplinary communities in biology pursued science in relative isolation Berkeley's organization in the biological sciences developed into an organization unified behind the goals of

[15] Personal communication Eileen Bell, Head of Graduate Affairs Office, Berkeley Department of Molecular and Cell Biology, May 21, 2004.

the biotechnology field even though industry actors did not become an integral part of this organization.

4.2. Stanford University

Stanford's biochemistry department was a small department with a number of principal investigators hovering around ten during the 1970s and 1980s.[16] Despite its small size, however, Stanford's biochemistry department was the top rated department in biochemistry in the United States during most of the 1980s and members of the department made key contributions to the scientific advances that formed the basis of the biotechnology industry. Moreover, members of the department would play important roles in major initiatives in the life sciences at Stanford following the rise of the biotechnology industry.

Like the group of molecular biologists at Berkeley's biochemistry department, the group of molecular biologists at Stanford's biochemistry department during the 1970s was a group that had carved out its own scientific program in a biological research environment that was fairly fragmented. The origins of Stanford's current biochemistry department date back to 1959 when the department was created as a core basic research department of the university's relocated medical school. Stanford's medical school was moved from San Francisco to Palo Alto to integrate the clinical practice of the medical school with the basic research organization of the university (e.g. Wilson, undated).

Stanford's biochemistry department was organized around a scientific program framed in terms that contrasted sharply with the scientific programs of other Stanford departments (Jong, 2006). Arthur Kornberg, the Nobel Prize winning biochemist, who was recruited to head the new department, organized it around a narrow disciplinary research agenda focused on the study of DNA in the context of simpler organisms. The faculty that Kornberg gathered around himself at Stanford had been recruited entirely from outside the university. Moreover, Kornberg isolated his department from other departments that in his eyes did not uphold similar scientific standards as he did. About the department's relationship to scientists of other departments involved in clinical research Kornberg (1998) for example noted the following;

> 'Clinical medicine to this very day constantly has to make adjustments that I would find distasteful in science. You deal with an individual, uncontrolled; you apply something, and you don't know whether it has been useful or not. I'm very respectful of clinical medicine because I'm a patient; my family members have been patients, and I'm curious about and interested in clinical medicine. But would I take a group of people from the department of medicine and include them as full and active members of the Biochemistry Department? In some cases, yes, but in a blanket way, no. And so the Department of Biochemistry here has had the reputation of being very exclusive, elitist, and we have not had the kind of joint appointments that are common in other institutions.'

The 1970s and early 1980s would be a period of organizational transformations for the life sciences at Stanford, in particular with respect to the institutional rules and norms governing relationships with industry. Focusing on developments at another, unidentified basic research department at Stanford's medical school, Colyvas (2007) highlights how patenting and licensing by faculty became an integral part of the scholarly process for many principal investigators following the rise of the biotechnology industry. Colyvas describes how an institutional framework developed within which industry ties became seen as a 'tool for furthering research and enhancing scientific reputation' (p. 473). In this environment the close proximity to Silicon Valley became seen as a key source of competitive advantage for scientists at Stanford in advancing their scholarly standing. Although not expressed in increases in patenting, a similar institutional shift can be observed at Stanford's biochemistry department.

Like at Berkeley, patenting activity by members of Stanford's biochemistry department was limited. Ronald Davis was the only principal investigator affiliated with the biochemistry department in 1981 who is listed as an inventor on patents filed during the 1980s.[17] Outside the realm of patenting and licensing however, members of the department developed close ties with the industry. The department set-up a successful industrial affiliates program in which firms paid a fee to gain access to faculty (Lenoir, 2002). In addition, members of the department developed close ties to industry as founders, collaborators and consultants of new biotechnology companies. Kornberg, who had been among the most skeptical about industrial involvement, became involved in a number of firms linked to the Silicon Valley entrepreneur Alex Zaffaroni. Moreover, Kornberg founded his own biotechnology firm, DNAX Research Institute of Molecular and Cellular Biology (DNAX) together with Zaffaroni, Paul Berg and Charles Yanofsky in 1980 (Kornberg, 1995).[18] 1980 was also the year when another member of the department, Douglas Brutlag co-founded IntelliGenetics, one of the first bioinformatics companies (Brutlag, 2004; Lenoir, 2002). Finally, the appointment of Ken-Ichi Arai, one of the chief scientists at the biotechnology firm DNAX, as a Consulting Professor at Stanford's biochemistry department signifies the realization that interaction with industry could be conducive to

[16] Number of faculty over this period obtained from Kornberg papers, available for consultation in the Special Collections and University Archives section of the Stanford Bing Wing Library.

[17] Patent search carried out through the search engine of the United States Patent and Trademark Office. Davis is listed as an inventor on five issued patents in total that were filed during the 1980s. List of faculty members of biochemistry department in 1981 obtained from Koshland Papers. It is interesting to note that the limited patenting activity by members of the biochemistry contrasts sharply with the active patenting by members of another basic research department in the life sciences at Stanford studied by Colyvas (2007).

[18] See Kornberg (1998) and Berg (2000), who describe how experiences with research organizations of large pharmaceutical firms had made Kornberg very skeptical about developing ties to industry and how this skepticism disappeared after Kornberg's first experiences with biotechnology firms, which encouraged scientists to remain actively involved in academic activities.

Table 3
Stanford biology departments 1969, 2006

	1969/1970	2006/2007
School of Humanities and Sciences	Biological sciences	Biological sciences
School of Medicine	Anatomy Biochemistry Genetics Medical neurobiology Pharmacology Physiology	Biochemistry Bioengineering Developmental biology Genetics Microbiology and Immunology Molecular and Cellular Physiology Molecular Pharmacology Neurobiology Structural biology

Source: Stanford Bulletin 2006–2007, Stanford Courses and Degrees 1969–1970.

both industrial innovation and academic scholarship (Kornberg papers).

Despite this embrace of new scientific programs linked to innovation in the biotechnology field, the organizational set-up of Stanford's biochemistry department at the end of the 1970s still reflected the focus on simpler organisms around which Kornberg had organized the department in 1959. Shifting the emphasis of scholarly enquiry to the study of genetic mechanisms in more complex organisms required access to expertise and skills beyond what was available within the biochemistry department. As a result, building up more encompassing scholarly networks of specialized expertise and skills around the biochemistry department became the core objective of initiatives promoted by institution-builders from the department during the 1980s and 1990s. Like their counterparts at Berkeley, members of Stanford's biochemistry department proved well positioned to achieve this objective as prominent scientists in scholarly networks closely tied to innovation in the biotechnology sector.

As Table 3 illustrates, growth of new biology departments at Stanford over the last decades has been concentrated within the medical school. New departments were primarily formed in subject areas opened up by new genetic engineering techniques to which members of the biochemistry department made important contributions, and not in subject areas, more detached from industry concerns, covered by the Department of Biological Sciences within the School of Humanities and Sciences.

Moreover, Fig. 2 illustrates the increased level of integration of scholarship in biology across departmental units at Stanford following the rise of biotechnology, highlighting changes in the percentage of publications of members of the biochemistry department that list authors tied to other Stanford departments as well. Whereas during the early 1980s, at the time of the formation of the biotechnology industry, such cross-departmental publications were very rare, by the dawn of the 21st century they constituted the majority. Fig. 2 thus suggests a decrease in the fragmentation of scholarly life that was characteristic of the organization of biology at Stanford before the rise of biotechnology.

Molecular biologists from Stanford's biochemistry department with close industry ties played an important role in defining the institutional frameworks, within which

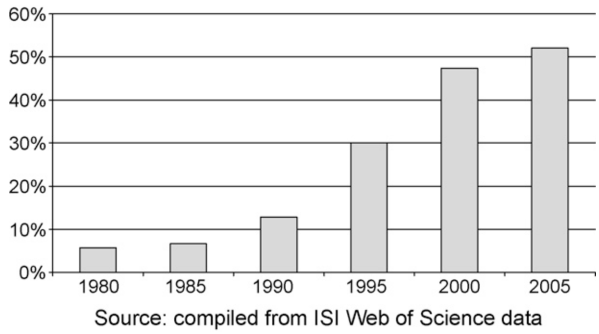

Fig. 2. Percentage of total number of publications by scientists of Stanford biochemistry department, listing a scientist tied to at least one other Stanford department.

common scientific programs in the life sciences emerged during the 1980s and 1990s. Through a series of initiatives that recast the framing of their scholarly activities in the light of advances in the biotechnology field, members of the biochemistry department were successful in strengthening their position on campus. In these initiatives molecular biologists opened up to scientists from other disciplines on campus and in a break with the past, the department started to grant joint appointments.

The most important initiative around which molecular biologists of the biochemistry department were able to mobilize support during the 1980s was the creation of the Beckman Center for Molecular and Genetic Medicine (Beckman Center) to which the department moved in 1989. Heading the creation and development of the Beckman Center was Paul Berg, one of the biochemistry department's two Nobel Price winners and co-founder of the firm DNAX. The creation of the Beckman Center was entirely funded through private donations totaling USD 60 Million, the largest of which was a USD 12 Million donation by Arnold and Mabel Beckman.[19]

[19] See Kornberg (1998) for details about the first unsuccessful attempts to attract funding from Beckman for a new facility for the biochemistry department based on a continued focus on existing research agendas. Berg (1991, 2000) and Kornberg (1998) both outline how the biochemistry department eventually was successful in gaining funding after recasting the mission of the future Beckman Center in more clinically oriented terms.

The key aim of the Beckman Center, which was built directly next to main facilities of the School of Medicine, was to bridge the gap that existed at Stanford between the pure basic research that members of the biochemistry department were engaged in and the clinical practice of the medical school. This aim of Berg's initiative reflected the stark shift in attitudes among senior members of the biochemistry department about the desirability of scholarly ties to practitioners (whether in medicine or in industry) as a means to advance scholarship in their field.

In addition to linking scholarship of the biochemistry department to scholarship of clinical research departments at the medical school, two basic research departments were created to join the biochemistry department in the new Beckman Center. The approaches that would be developed within these departments were expected to complement those developed by biochemists and aid efforts to shift their scholarly focus to the study of more clinically relevant research topics. The new Department of Developmental Biology would focus on the basic biological mechanisms of human development and the new Department of Molecular and Cellular Physiology would focus on cell signaling and behavior, and on how cells coordinate their activities to form a working organism. In addition, in order to further integrate the activities of molecular biologists with the expertise of more clinically oriented scientists, Stanford's Howard Hughes Medical Institute was also concentrated in the new Beckman Center.

Furthermore, like Koshland at Berkeley, Berg at Stanford sought to strengthen the appeal of Stanford to graduate students through the creation of the Beckman Center. As the biotechnology sector matured during the 1980s, placing students in top industry positions became a factor determining a university's ability to attract the best graduate students. Like at Berkeley, Stanford's biochemistry department was increasingly facing challenges in attracting the best graduate students as these students opted to go to universities such as Stanford's Bay Area competitor, the University of California at San Francisco, which offered a more general, interdisciplinary program.[20]

As a part of the move of the biochemistry department to the Beckman Center in 1989, Berg attempted to create a unified doctoral program that would integrate the biochemistry department's doctoral program into the programs of other biomedical research departments at Stanford. This attempt encountered resistance from scientists who were afraid of loosing the special character of individual programs to the point that Berg's interdisciplinary doctoral program within the Beckman Center initially ran parallel to the individual program of the biochemistry department.[21] Only when the problems individual departments faced in student recruitment had become more apparent was Berg able to overcome resistance against his unified program. A new general biosciences program at Stanford that substituted the individual graduate programs of the various biomedical research departments at Stanford was finally created in 1995.[22]

Subsequent initiatives promoted by members of Stanford's biochemistry department during the 1990s further broadened scholarly networks mobilized around their scientific programs. These initiatives also increasingly incorporated industry actors as a part of the organizational design. One of the key initiatives that emanated from Stanford's biochemistry department was an initiative in the context of Stanford's genome sequencing efforts led by Ronald Davis. Davis was a member of the biochemistry department and an academic pioneer in the field of genome sequencing. In 1993, Davis became the founder and director of the Stanford DNA Sequencing and Technology Center (currently Stanford Genome Technology Center).[23]

In the DNA Sequencing and Technology Center, Davis brought together scholars from a wide range of disciplines around efforts from inside but also from outside the biological sciences to contribute to new technologies in the field of genome sequencing. Moreover, Davis viewed access to networks of expertise and skills in industry as key to exploiting the 'natural synergism between biology and technology' and the scholarly success of the Sequencing and Technology Center.[24] Davis had longstanding ties to the biotechnology industry, which dated back to the 1970s; to foster industry collaborations the DNA Sequencing and Technology Center was located away from the core university campus, in the Stanford Industrial Park.[25] Apart from turning the Stanford DNA Sequencing and Technology Center into Stanford's most important contributor to the human genome project (Thacker, 2005), the center developed into one of the hotbeds of entrepreneurship in the Silicon Valley biotechnology cluster. The DNA Sequencing and Technology Center spun-off around 12 companies, including Affymetrix and Gene Machines (Bowers, 2002).

Another initiative promoted by faculty of the biochemistry department that finds it roots in the 1990s was the development of Stanford's Bio-X initiative, which would have a budget of around USD 210 Million. This initiative took shape during the late 1990s thanks to the efforts of a group of faculty members headed by James Spudich, a professor of biochemistry, who also co-founded the biotechnology firm Cytokinetics. The Bio-X initiative was aimed to complement scholarly life at the Beckman Center and broaden the scholarly coalition at Stanford aimed at pursuing new scientific opportunities in the life sci-

[20] Berg (2000) discusses Stanford's challenge in competing with more interdisciplinary graduate programs, primarily UCSF's Program in the Biological Sciences (PIBS), which was started in 1988. Extensive documentation on PIBS and its success is available for consultation from the Bruce Alberts papers, Special Collections and University Archives of UCSF Kalmanovitz Library.

[21] See Berg (2000) for a discussion of initial resistance by fellow faculty members of the biochemistry department to give up autonomy in organizing graduate training during the late 1980s and early 1990s.

[22] See Berg (2000) for a discussion of the interdisciplinary program in molecular medicine at the Beckman Centre and the eventual integration of the biochemistry program into this program.

[23] During the Center's early days David Botstein, a Stanford geneticist and former vice president for science at the biotechnology firm Genentech served as the center's co-director.

[24] See http://med.stanford.edu/sgtc/ (last accessed January 22, 2008).

[25] Davis joined the scientific advisory board of one of the first biotechnology firms Collaborative Genetics in 1979 (Wade, 1980).

ences. Although some faculty members mostly without a strong interest in molecular biology claimed that already enough resources had been allocated at Stanford to satisfy the needs of scholars with an interest in the biotechnology field, the Bio-X initiative enjoyed the strong support of Stanford's President Gerhard Casper and the university's Provost Condoleezza Rice (Kruger, 2004).

Central to the program was the creation of a new facility in close proximity to the Beckman Center and the School of Medicine that was completed in 2003. The aim of the new Bio-X facility was to bring together around a therapeutically relevant biomedical research agenda scientists from a wider set of departments than the Beckman Center, and on a larger scale. The Bio-X facility would therefore not only house faculty members from the School of Medicine but also faculty members from the Schools of Humanities and Sciences, Engineering, Earth Sciences and the School of Law.

Something that further underlines the changed attitudes among Stanford's previously 'industry wary' biochemists was that the Bio-X initiative was developed in coordination with the entrepreneurial community of Silicon Valley, of which many of Stanford's biochemists had now become a part. As a part of the Bio-X initiative, the Stanford Advisory Council on Interdisciplinary Biosciences, was created, which not only would include eminent biologists, but also executives from local biotechnology firms and venture capitalists (Kruger, 2004). Moreover, the largest of the private donations that funded the development of the Bio-X initiative came from Jim Clark, who apart from being a former Stanford Professor had founded a number of Silicon Valley firms including Netscape and Silicon Graphics.

Thus, major expansionist initiatives by members of Stanford's biochemistry department with close industry ties played an important role in shaping the history of the life sciences at Stanford. Over the 1980s and 1990s, the biochemistry department developed into an important node in a wide network of scholarly expertise and skills at Stanford united by a set of common scientific objectives. Moreover, the organizational frames used by institution builders to structure their initiatives increasingly incorporated industry actors as key actors in the scholarly process.

5. Discussion

Initiatives emanating from Berkeley's and Stanford's biochemistry departments following the rise of biotechnology underline how new science-based industries have the potential of upsetting local social orders in modern science. These industries not only alter the way scientists live their professional lives inside scholarly communities, they also alter the position of scholarly communities in relationship to other communities within a university. The two discussed cases bring into sharper focus the processes of organizational adaptation within universities that follow the rise of new science-based industries. This article has highlighted how these processes at different universities are determined by constraints local rules and norms impose on efforts by institution-builders to use the practical relevance of their work to prevail in struggles for scholarly legitimacy. The creation of new academic units by members of Berkeley's and Stanford's biochemistry departments in particular illustrates two levels at which organizational outcomes of such efforts are shaped by the institutional environment of scientists.

1. The presented case studies link processes of organizational adaptation to rules and norms that define the relationship of universities to their external environment. American universities have historically tended to put an emphasis on subjects of practical relevance (Rosenberg and Nelson, 1994; Ben-David, 1977). The cases of Berkeley and Stanford provide a more detailed insight into the dynamics that contributed to this emphasis. The way in which institution-builders in molecular biology at Berkeley and Stanford during the 1980s and 1990s successfully used social frames to appeal to the concerns and interests of the external actors on which they rely for legitimacy was similar in important respects.

   The external patrons institution builders relied on in pursuing their expansionist initiatives at these two universities were not identical. In particular during the 1980s, space for the development of new scholarly initiatives at Berkeley was dependent on support from the Californian state legislature. In contrast, Stanford relied mostly on private donations to fund major infrastructure investments tied to the expansionist initiatives molecular biologists promoted during this period. The needs and interests of both private and public patrons the expansionist initiatives of molecular biologists at Berkeley and Stanford appealed to were however mostly similar. In both cases, patrons sought to achieve aims mostly defined in practical terms, be it focused on the ability of science to foster industrial competitiveness in the case of the State of California or on the ability of science to cure human diseases in the case of Arnold and Mabel Beckman.

   Apart from highlighting the frames used by institution-builders in legitimizing expansionist initiatives, the Berkeley and Stanford cases offer important insights into the social position of the institution-builders that successfully used these frames. A key similarity emerges between the roles played by leaders of the organizational realignments at Berkeley and Stanford in innovation networks in the life sciences; these leaders not only stood out among their peers because of their academic work but also because of their close involvement in industry. Thus, the extent, to which scientists occupy central nodes in both academic and industry research networks appears an important factor that determines the success of these scientists in strengthening the legitimacy of their scientific programs.

   Moreover, while ties to industry forged following the rise of biotechnology help better understand the success of expansionist initiatives in molecular biology during the 1980s and 1990s, the absence of these ties is an important factor that explains the failure of similar initiatives during the 1950s and 1960s. During the decades preceding the formation of the biotechnology industry, molecular biologists had attempted at numerous occasions to pursue initiatives aimed at expanding networks of skills and expertise they could rely on in their research. Moreover, the promise of practical innovations formed a key part of the legitimating account of molecular biology since the inception of the field (e.g. Creager, 1996; Judson, 1996). However, only after these molecular biologists had become involved in solving actual practical problems in industry were they able to appeal to external patrons to end the stalemate that had characterized struggles for legitimacy in biology at Berkeley and Stanford up to the 1970s. The presented case studies thus suggest that the absence of links to practitioner communities in industry or elsewhere constitutes a disadvantage for institution builders in their ability to appeal to the utilitarian concerns of actors outside the university.

2. The presented case studies link divergent processes of organizational adaptation following the rise of a new science-based industry to constraints imposed by local institutional rules and norms governing scholarly enquiry within universities. Although molecular biologists were similarly successful in mobilizing support for expansionist initiatives, the design of academic units that resulted from these initiatives were shaped by distinctive models of technology transfer at Berkeley and Stanford. The findings of this study confirm that whereas at Berkeley the advancement of knowledge in science was seen as mostly separate from industrial concerns, at Stanford an organizational tradition had taken shape by the 1980s, in which the exposure to practical concerns was seen as conducive to the advancement of scholarly knowledge. Ties to practitioners, in particular in industry were more accepted as an integral part of the scholarly process at Stanford than at Berkeley. In fact, the design of initiatives emanating from Stanford's biochemistry department illustrate that the opportunity to develop ties to the Silicon Valley high-tech community was seen as a key source of comparative advantage for Stanford scholars.

   Colyvas (2007) in her study on the incorporation of patenting in research practices in the life sciences at Stanford highlights the extent to which the legitimating accounts underlying these practices were shaped by a view in which industry ties were seen as conducive to academic scholarship. Such a view permeated also the organization of new institutional initiatives in the life sciences. The design of the initiatives discussed in this paper reflect numerous ways in which institution builders sought to leverage practitioner ties to advance academic scholarship at Stanford. A key aim of Paul Berg in setting up the Beckman Center was to foster research interactions between clinical practitioners and molecular biologists. Moreover, members of the Silicon Valley industry community were assigned important roles in the design of the Bio-X initiative and the Stanford DNA Sequencing and Technology initiative.

   In contrast, underlying the organizational design of major initiatives led by Berkeley's molecular biologists was a more traditional 'linear' view of the innovation process, in which academic research and industrial development were seen as separate, consecutive steps in the innovation process. The cited quote by Robert Tjian, in which he dismisses the impact of his close involvement in firms on his scientific research 'at the ground level' contrasts sharply with the close links members of Stanford's biochemistry departments such as Ronald Davis drew between their industry ties and academic successes in the development of their institutional initiatives. As a result, although the biotechnology industry figured prominently in the narratives used to legitimize major expansions in molecular biology at the university, industry was kept at arms-length from the academic units where these expansions took shape. For example, industry actors were not assigned a role in the design of the initiatives headed by Daniel Koshland and Robert Tjian.

6. Conclusion

This study on organizational changes in the life sciences at Berkeley and Stanford following the rise of biotechnology sheds a new light on how institution builders seek to leverage industry ties in the context of struggles for legitimacy within their university. Most importantly, by recasting processes of organizational change within universities as shaped by local political struggles among scholarly communities for legitimacy, this study illuminates how the interplay between scientific institution builders and their broader organizational environment shapes the advancement of knowledge in modern science. A number of avenues remain open for further investigation.

Firstly, the empirical focus of this study has been squarely on the small groups of molecular biologists at the biochemistry departments of Berkeley and Stanford and not on other groups. This study highlights the consistent resistance of scholarly communities in other fields of scientific enquiry in the biological sciences against molecular biologists' expansionist initiatives before (successful) and after (unsuccessful) the rise of biotechnology. However, the fate of the networks of expertise and skills these other scholarly communities represented, has remained largely unaddressed. Additional research, perhaps in the context of universities that remained more detached from the biotechnology field will need to shed a light on the impact of the rise of new science-based industries on the development of scholarly communities that are not linked to these industries.

Second, the primary outcomes this study focused on were the organizational set-up and legitimating accounts underlying new academic units and indicators of control over these units. The extent to which the creation of these units altered day-to-day academic and commercial activities of members of the examined scholarly communities was not a primary concern of this study. Unveiling in a systematic way how the creation of new organizational units by academic institution-builders with close industry ties has an impact on the day-to-day professional lives of the scholarly communities that move into these units is also a topic that deserves further attention.

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