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Abstract

Recent studies link the performance of regional technology clusters to their social organization. In an influential study of the success of Silicon Valley, Saxenian (1994) argues that the region benefits from a decentralized structure encouraging the formation of diffuse social ties linking scientists and engineers across local companies. This article examines the emergence of social structures supporting biotechnology across three regions of California: San Francisco, Los Angeles, and San Diego. Social network analysis methods are used to trace the formation of social ties linking some 2500 senior managers working within California biotechnology between 1976 to 2005. Findings show that San Francisco biotechnology succeeded quickly because it inherited an appropriate social structure for the sector from the Silicon Valley electronics industry. San Diego, on the other hand, was a region with no previous high-technology. Social networks supporting biotechnology were constructed in the region through the unanticipated collapse of an early key firm, Hybritech, which lead to the formation of over a dozen spin-offs linked through founder networks. Los Angeles, despite being home to the industry's leading firm, Amgen, has not developed a successful biotechnology industry, nor has it developed a social structure to support marketplace formation in the region. In sum, through exploring scenarios by which social structures supporting high-technology industry emerge (or, in the case of Los Angeles, fail to emerge), the article aims to contribute to broader debates theoretical exploring the sociological basis of economic development.

Keywords:
Social networks, biotechnology, entrepreneurship

Social Structure and Marketplace Formation within California Biotechnology

Clusters of high-technology firms have become an important source of economic development across the advanced industrial economies (Storper 1997; Braunerhjelm and Feldman 2006). Recent studies of technology clusters have linked their performance to their economic and social organization. A central explanation focuses on the organization of social structures within technology clusters. In an influential study of the success of Silicon Valley, Saxenian (1994) argues that the region benefits from a decentralized structure encouraging the formation of diffuse social ties linking scientists and engineers across local companies helps diffuse innovation, while from the point of view of skilled individuals, manage the career risks of working in failure-prone companies. This explanation emphasizes the social embeddednes of economic action, as companies embedded within regions with a decentralized culture of high mobility and knowledge diffusion will have a "regional advantage" over companies that are not (Saxenian 1994; Herrigel 1994; Sabel 1992).

While providing a persuasive explanation for the success of some regional clusters over others, a difficulty with the social structure explanation is that it only makes sense once a large agglomeration of companies coupled with norms and social networks encouraging inter-firm mobility and communication exist. Left unexplored are the mechanisms by which regions move from a starting position in which neither the agglomeration of companies or decentralized social structure exist to one in which they do. How do regional technology clusters, and the social structure underpinning them, emerge and become sustainable?

This article examines the emergence of social structures supporting biotechnology across three regions of California: San Francisco, Los Angeles, and San Diego. The article draws on social network analysis methods to trace the formation of social ties linking some 2500 senior managers working within California biotechnology. The characteristics of social networks are mapped within California from the initial commercialization of biotechnology in San Francisco by Genentech in 1976, up until

2005. The study is designed to create a lens by which explore mechanisms by which social ties linking companies within technology clusters emerge.

California biotechnology also poses an interesting puzzle: while world class universities, which are widely seen as a prerequisite for the emergence of biotechnology firms (Darby and Zucker, 1996), existed in each of the three regions studied, only two of them, San Francisco and San Diego, have developed successful biotechnology clusters. Los Angeles, despite being home to premier research institutes such as the California Institute of Technology and one extremely successful early biotechnology company, Amgen, has not developed a sustainable biotechnology industry. While the San Francisco and San Diego regions have each launched over 200 biotechnology firms and have seen about 65 companies reach the significant goal of attaining an initial public offering on a stock market, only 31 biotechnology companies have been founded in Los Angeles between 1980 and 2005. Moreover, of these firms, only Amgen has become publicly traded through an IPO. The study will demonstrate that the divergent performance across these clusters can at least partly be explained by the social structure approach: both San Diego and San Francisco succeeded in developing decentralized social structures supporting companies, while Los Angeles has not.

The study explores differences by which decentralized social structures supporting biotechnology emerged in San Francisco and San Diego. Drawing on institutional theory, the article will argue that individuals employed within the San Francisco biotechnology industry *ihherited* norms Silicon Valley legitimizing the establishment of social ties across companies and sanctioning frequent career mobility across firms. Genentech and other early biotechnology companies benefited from being located in close proximity to Silicon Valley. The area's early firms inherited norms encouraging information sharing and flexible labor markets that were common within the region's semiconductor and computer industry.

The San Diego region, on the other hand, was not home to a significant high-technology industry prior to the launch of its first biotechnology firm in 1978. To explore mechanisms of social structure emergence in "greenfield" regions such as San Diego, constructivist approaches are appropriate (see e.g. Sabel, 1993). A key theoretical metaphor from social network studies surrounding social structure construction surrounds the development of a "backbone" of social ties within a region. Once formed, these ties serve as a resource for companies, thus increasing their innovative capacity. Moreover, they form the basis of a credible referral network other individuals could tap into to obtain jobs and, as the network expanded, reduce the career risk of working within one of the region's technology companies. Within San Diego a network background emerged through the failed acquisition of Hybritech, a prominent and successful early company. Due to poor management practices by the acquiring company, a cadre of at least two dozen senior managers and scientists left Hybritech within the first two years after the acquisition. They went on to form the backbone of entrepreneurial networks linking most of the region's core biotechnology companies, and through doing so spurring the rapid growth of biotechnology in San Diego.

Through exploring scenarios by which social structures supporting high-technology industry emerge (or, in the case of Los Angeles, fail to emerge), the article aims to contribute to broader debates exploring the sociological basis of economic development. While California biotechnology developed without direct policy intervention, governments around the world have in recent years attempted to orchestrate the development of biotechnology clusters. However, empirical studies have shown that there are very few successful high-technology clusters. San Francisco and San Diego represent two of only three large and successful biotechnology clusters in the world (Boston is the third). If successful clusters are linked to the establishment of a decentralized social structure, cases of their successful emergence might be extremely rare. Documenting mechanisms of emergence across the few successful clusters that do exist is an important step in designing comparative research capable of yielding generalizations applicable across clusters and, from the perspective of public policy, evaluating whether governments can usefully intervene in this field.

Social structure and the sustainability of technology clusters

While a long tradition of research has sought to explain industries often agglomerate within regions (see e.g. Freeman and Soete 1997 for a review), the central argument linking social structure to the performance of regional high technology clusters was developed by Saxenian (1994) through a comparison of the Silicon Valley and Route 128/Boston regional semiconductor industries (see also Almeida and Kogut 1999 and Fleming et. al. 2005 for follow-up studies on Silicon Valley, and Herrigel 1993 for a similar argument applied to Baden Wurttemberg in Germany). Saxenian argues that Silicon Valley's success is linked to the development of a decentralized social structure encouraging the development of numerous informal links across the region's scientists, engineers, and managers. Norms legitimizing frequent contact between scientists and engineers working across organizations is an important element of this social structure. However, Silicon Valley has also been shown to have unusually high job mobility (Saxenian, NN; Almeida and Kogut 1999), helping to generate dense social networks linking employee's of the region's firms.

Two mechanisms exist whereby the development of a decentralized social structure might raise the performance of companies within a region. First, social ties linking scientists, engineers, and managers across organization can help diffuse knowledge across a region's firms. In particular, embededness within a decentralized social structure may provide a competitive advantage for technology-intensive firms operating in market segments in which technological volatility is high. To give an example from biotechnology, Pennan (1996) conducted a bibliometric survey of approaches being used to develop therapies for Alzheimer's disease and found over 20 distinct technological approaches being pursued by competing teams of biotechnology firms, basic research labs, and large pharmaceutical companies. Within highly competitive new technology fields such as this, informal ties across firms may provide market or technological intelligence, allowing companies to make superior decisions as to which technologies to adopt or, at times discontinue. Firms may be able to react to market developments faster than competitors.

Second, decentralized social structures may also provide companies with an edge in recruiting highly skilled employees. The success of technology start-ups is in part determined by their ability to entice skilled managers and employees to leave lucrative and often 'safe' jobs in established companies or universities to join a new venture (Whitley 2004; Baron and Hannan, 2002). Skilled employees and managers are typically given grants of company stock or stock-options as an incentive to join work intensive start-ups (Kenney and Florida 1988). Should the company succeed and "go public" through a stock offering or be acquired at a favorable valuation early employees can earn vast payouts (Lerner and Gompers 2001). However, the potential benefits of working within a start-up are countered by a high likelihood that employment tenures within start-ups will be short due to dismissals or outright failure. Most start-ups fail to reach a lucrative exit, be it an initial public offering or acquisition by a larger firm at a favorable valuation. Venture capitalists often decide to halt investments in new technology companies that fail to meet key milestones. Dismissals of top management are often a common response by VC-led boards to firms that have failed to meet development milestones. Managers and employees within start-ups also find themselves at risk of dismissal due to strategic decisions to change the competency structure of the firm. Moreover, as a condition to invest, many venture capitalists insist that early technical founders of companies often need to be replaced by professional managers as a company develops.

From the point of view of individuals, there is a strong rationale for choosing to work only within start-up companies embedded within a regional cluster in which social ties promoting mobility are strong. Doing so can dramatically lower the career risk for founding teams and R&D staffs by creating numerous alternate employment options should a given venture fail, undergo managerial shakeups at the behest of investors, or need to change its competency structure due to technological volatility (Bahrami and Evans 1999). This helps explain why successful and presumably risk adverse scientists and managers would give up prestigious careers in established companies or university labs to work within lucrative but highly risky start-ups: within successful clusters the embeddednes of individuals within social networks makes it safe to do so. To quote Saxenian, "Moving from job to job in Silicon Valley was not as disruptive of personal, social, or professional ties as it could be elsewhere." (Saxenian 1994: 35).

While focusing attention on explaining successful cases, and especially Silicon Valley, the social structure approach also contains an explanation of why most regional economies fail. Most clusters, even if they reach sufficient size, do not develop the social networks or norms of high labor market flexibility needed to create the 'regional advantage' associated with Silicon Valley. Lacking a safety net provided by career affiliation networks, leaving a safe job to work within a failure prone start-up is truly a risky proposition, one that risk-averse individuals will likely resist. According to Saxenian's research, for example, the decline of Boston/Route 128's computer and semiconductor industry was influenced by autarkic practices of long-term employment within its companies that hindered the creation of flexible labor markets, along with norms within many companies that shunned informal information sharing across companies. This limited the capacity of the area's companies to adapt challenges created by the development of the personal computer industry in Silicon Valley in the early 1980s (Saxenian 1994, ch. 3).

Comparative research suggests that very few technology clusters have achieved either the critical mass of companies or regional innovative advantage associated with Silicon Valley. In the biotechnology industry, for example, only three large regional clusters exist, in San Francisco, San Diego, and Boston, despite the introduction of dozens of policy initiatives aimed at creating biotechnology clusters across the world (see e.g. Romaneli and Feldman 2006 for evidence from the United States and Casper 2007 for research on Europe). Research on the semiconductor industry has also found that very few large regional clusters exist. Almeida and Kogut, for example, followed-up Saxenian's research with a quantitative study using patent data from twelve US semiconductor clusters. Patent data was used to gather information on levels of inter-firm mobility of inventors within each cluster and as an indicator of aggregate innovativeness. Their study supported Saxenian's argument, showing that only Silicon Valley had both high levels of job mobility, presumably facilitated by a decentralized social structure, as well as a higher innovative capacity documented through markedly higher levels of patenting.

Social networks and the emergence of social structure

The rarity of well-performing clusters suggests that the development of an appropriate social infrastructures to support new technology companies a difficult problem, perhaps one rarely solved. The issue of emergence, of moving essentially from "nothing" to the generation of a decentralized social infrastructure capable of diffusing innovation and facilitating career management, has only begun to be systematically examined (see e.g. and Uzzi and Spri 2005; Flemming 2004; Kogut, Urso, and Walker 2007) This study draws on two different approaches within research on social theory to conceptualize the emergence of social structure. A first, *constructivist* approach emphasizes the agency of individuals, companies, and other social actors to build the necessary social infrastructure needed to orient the behavior of individuals towards a desired pattern. A second, *institutional* approach emphasizes the importance of overarching or preexisting rules or norms governing economic activity within a given locality. Applied to the emergence of regional technology clusters, appropriate social structures for a local technology cluster will develop when actors inherit pre-existing norms of behavior within a region that are conducive towards its formation.

Constructivism and the emergence of new social structures

The first approach draws on constructivist theories within sociology and political science (see e.g. Sabel 1993; Ruggie 1998; Berger and Luckmann 1967). This approaches encourages an agency centered perspective, focusing on processes by which social actors to develop the social ties, norms, or institutions needed to govern their activities. The key conceptual task of this approach is to explore scenarios by which actors within a region may plausibly construct the patterns of social ties that may coalesce into a more enduring social structure. The constructivist approach seems particularly appropriate for examining regions that currently do not have a significant technology industry, and thus must develop social structures needed to support it.

The rarity of well-performing technology clusters suggests that the construction of a decentralized social structure is difficult to achieve. Decentralized social structures likely share characteristics analogous to a collective or public good: its benefits accrue to most if not all individuals and companies within the regional economy. However, unlike traditional public goods maintained by governments or other dominant actors (roadways, the air), social infrastructures supporting technology clusters may be difficult to orchestrate or maintain in a systematic fashion. Rather, it is an emergent property, a product of the collective behavior of individuals and firms within a regional economy.

As such, it is unlikely that individuals or firms can single-handedly develop the necessary mesh of social ties needed to sustain a highly innovative cluster. A relatively large number of individuals must develop and mobilize social relationships in order to develop a density of ties sufficient to generate an overarching social structure capable of providing benefits to firms and individuals. What are the mechanisms by which regions move from a starting position in which neither the agglomeration of companies or social networks underpinning mobility exist to one in which they do?

One potential logic of emergence is that social networks develop slowly or incrementally. Early entrants to a cluster might be particularly risk acceptant individuals. They might enter due to extraordinarily attractive opportunity conditions associated with the technology they are attempting to commercialize, either because the industry is new or because their particular technology is seen by experts in the field as representing a particularly strong value proposition. Once one or more early companies are established in a region and experience success, additional companies might be encouraged to enter a local industry. If key individuals from early companies take jobs at new firms, or, as well documented in the early development of Silicon Valley (Lécuyer 2006), are encouraged to found start-ups, social ties linking a region's firms will begin to develop. As a region's nexus of companies continues to expand social ties might increase in density. It is possible that, after reaching a certain size and rate of mobility, a tipping point could be reached whereby the cluster becomes sustainable and regional innovation effects begin to accrue.

There are two difficulties with this explanation. First, social network effects may only be pronounced once a large number of individuals participate in the network; benefits may only develop as social networks become relatively large and efficiently organized. If so, early pioneers within a cluster may be particularly failure prone. Early failures are likely to be much more costly, in terms of their effects on social network growth, than later failures. This is both because of possible negative demonstration effects within the region created by early failures, and because individuals employed by these early firms will have fewer local job opportunities and might be more likely to return to "safer" jobs in more stable organizations or seek employment in entrepreneurial firms outside the region. If so, nascent technology clusters might never reach the critical mass to become sustainable.

Second, early companies might succeed, but develop inward focused corporate cultures and human resource policies that shun extensive personnel mobility into and out of the company in favor of long-term employment policies. Saxenian's (1994) research on the Boston/128 computer industry documents this scenario. Companies adopting autarkic strategies will not contribute significantly to social network development within a region. There is also a possibility norms "imprinted" on follow-on companies within the region will follow similar inward-focused corporate cultures. Within the Los Angeles region social networks have failed to develop across companies. While this study will not explore the cause of this failure in detail, a recent history of the region's dominant biotechnology firm, Amgen, suggests that the firm has developed an inward looking culture favoring long-term employment and a policy of filling most vacancies with internal promotions (Binder and Bashe 2008, ch. 9-10).

If the gradual construction of social ties within a region is problematic, perhaps social structures may be engineered, in a sense, to develop more rapidly. A key theoretical metaphor here is that, to gain momentum, a "backbone" of social ties must exist in a region (Powell et al 2005). Once formed, these ties can serve as resources for companies, thus increasing their innovative capacity. Moreover, they would form the basis of a credible referral network other individuals could tap into to obtain jobs and, as the network expanded, reduce the career risk of working within one of the region's technology companies. The credibility of this early network would increase to the extent that prominent individuals within the region were linked into the network.

A key problem with the orchestrated approach is identifying mechanisms to rapidly construct social networks. One approach, which would have important public policy implications if valid, is for governments is to orchestrate the "seeding" of a cluster's early development. This approach has been used frequently around the world, perhaps with some success in areas such as Munich, Germany (see e.g. Casper 2007). However, in California there is little evidence that governments have actively orchestrating cluster development. Rapid social network construction did occur in San Diego, primarily as a consequence of the failed acquisition of Hybritech. Reviewing this case will demonstrates that social network backbones quickly form within a local market context, but also suggests that this occurrence might be contingent on factors difficult to orchestrate through, for example, public policy.

The institutional approach and the inheritance scenario

Institutional approaches views the establishment of a dense network of social ties linking firms within a regional economy as the outcome of broader legal rules and norms within the region that sanction or encourage this behavior (see e.g. DiMaggio and Powell 1983). Institutional research focuses on enduring patterns of behavior created by legal frameworks, but also rules and norms created over time as a result of the social interaction of actors (see e.g. North, 1992). Within the realm of regional cluster development, a prominent example of the institutional perspective stems from recent research on Silicon Valley linking the prevalence of job-hopping to state laws in California that strike down "non-compete" clauses that can create barriers to employees moving to similar jobs in rival companies (see Hyde 1998; Gilson 1999). This legal rule clearly encourages inter-firm mobility and may be a catalyst for the formation of decentralized social structures. However, it by itself cannot explain the divergence of case outcomes across California's three major biotechnology clusters, particularly the failure of Los Angeles biotechnology.

From the institutional perspective, the formation of a new technology cluster may be strongly impacted by the existence of norms and rules within a region structuring the behavior of individuals within companies. Participants in a new industry may *inherit* patterns of behavior previously established in a given region. If rules and norms lead to the more autarkic of company focused patterns of behavior, in which employees do not regulatory share information with other regional companies and local norms focus on long-term loyalty to established companies, then strong networks of ties linking companies are unlikely to develop. On the other hand, if rules and norms within a region sanction communication between individuals working within different firms and legitimate frequent job hopping across firms, especially the act of leaving one's firm to found a new, often competing enterprise, then decentralized social structures will develop.

The San Francisco biotechnology industry is strong candidate to have inherited its social structure from the preexisting Silicon Valley computer and semiconductor industry. The region was first to establish a biotechnology industry. While the emergence of biotechnology in the San Francisco region was critically influenced by the invention of key genetic engineering and related molecular biology techniques at UCSF and Stanford, Genentech and other early biotechnology spin-outs benefited from being located in close proximity to Silicon Valley. The area's early firms inherited norms encouraging information sharing and flexible labor markets that were common within the semiconductor and computer industry.

Research Design

The study uses social network analysis tools to examine how social structures emerged within regional biotechnology industries located across California's three major regions: San Francisco, San Diego, and Los Angeles. Social network analysis tools can be used to map out the architecture of such ties and compare their characteristics over time (Faust and Wasserman, 1996). If a social structure facilitating high levels of exchange and career mobility across companies is indeed a determinant of success within regional technology clusters, then comparing the structure of social ties across multiple regions, and especially how these structures change over time, can be a useful research strategy.

The study examines the emergence of *career affiliation networks* formed between *senior managers* of California biotechnology firms on the basis of ties between individuals that are formed through joint employment at the same organization (see Casper 2007). Within the biotechnology industry senior management usually includes a company's chief executive, chief scientific officer, chief finance officer, and a number of vice presidents and senior personnel involved in research and development, business development, and, within some companies, human resources and legal affairs. Senior managers must define a firm's strategy and mobilize the necessary resources to implement it. Recruiting talented senior management is strongly linked to the success of biotechnology companies (Gulati and Higgins 2003). In this respect, an emphasis on top management again links directly to the emphasis on career mobility.

The study traces the emergence of social networks linking senior managers employed over the history of California's biotechnology industry, beginning with the founding of Genentech in San Francisco in 1976 and concluding in 2005. Social networks linking 2285 senior managers employed in 448 California biotechnology firms established between 1976 and 2005 are analyzed. As a supplemental database, career histories for all *founders* of each region's biotechnology companies was also created. This database includes 505 founders, but includes several dozen academic founders of companies that did not leave their university job to work full-time as a biotechnology managers, and are thus not included in the social network analysis.

The biotechnology industry was chosen for study due to its status as a high technology industry containing high technological volatility (see Henderson, Orsenigo, and Pisano 1999). Opportunity conditions in biotechnology are often attractive, as large, multi-billion dollar markets exist for drug and diagnostics products meeting unmet medical needs, and intellectual regimes surrounding new treatments are strong. While a few successful firms have generated enormous profits, failure rates are high in the biotechnology industry (see Pisano 2007). Most companies eventually fail or are cheaply acquired and integrated into competitors or large pharmaceutical companies. An Internet database located within the Biotech Career Center (2006) lists several hundred failed companies. Given both technological volatility and high failure rates, biotechnology is an industry in which resources provided to firms and their employees by the existence of a decentralized social structure are likely to be significant. Moreover, a key theme emerging from research on the biotechnology industry is the decentralization of knowledge within the industry and the need for companies to develop and tap into a variety of external networks if they are to succeed (Powell 1996; Powell, Doerr, and Koput 1996; Shan, Walker, and Kogut 1994).

Following Powell et. al. (2005) the study focused primarily on biotechnology companies specialized in human therapeutics and molecular diagnostics. Only research intensive and independent biotechnology companies were included in the database; local subsidiaries of corporations headquartered outside California were not included.

However, a small number of companies were included in the areas of agricultural biotechnology and so-called platform biotechnologies (such as DNA chips and related assays) that were clearly R&D intensive, drew from university research, and were initially financed through venture capitalists. Medical device companies and engineering or "hardware" related platform biotechnology companies in areas such as instrumentation were not included in the study

California is an excellent laboratory to study cluster development. As mentioned earlier, the study's research design selects two successful cases, San Diego and San Francisco, and one failure case, Los Angeles. The variance in outcomes across California's three core regions is interesting given their geographical proximity and exposure to identical national and state level legal frameworks regulating both business and the commercialization of science. Moreover, the focus on California allows the research design to plausibly control for one factor that is crucial to the development of commercial biotechnology: the existence of world-class university research in the biosciences. The importance of university-firm ties has led to the establishment of most biotechnology clusters in close proximity to leading universities (Zucker et. al. 1999; Murray 2004). Each of the three regions studied has several leading universities, medical schools, and research institutes focused on the biosciences. San Francisco is home to Stanford University, the University of California Berkeley, and the University of California San Francisco. The Los Angeles region houses the California Institute of Technology, the University of California Los Angeles, the University of Southern California, and several large research oriented hospitals, such as the City of Hope and the Children's Hospital Los Angeles. San Diego has long been home to several world class biomedical research institutes, such as the Scripps Research Institute and the Salk Institute, while the University of California, San Diego has developed a medical school and strong departments in chemistry, biology, and other fields with links to biotechnology.

Methods: data gathering and network construction

The research process has three steps: locating firms, gathering career histories of senior managers, and then using social network analysis tools and related descriptive statistics to gather and analyze results.

Company demographics within California biotechnology

High failure rates within the biotechnology industry make the identification of firms over the history of a regional cluster difficult. A first step was to locate biotechnology companies active at the time of data collection for the study. A published industry directory of the California biotechnology industry (Rich's, 2006) and several on-line directories were used as initial screen to identify companies in each region. The first part of the search yielded 319 biotechnology companies active in 2006.

The second part of the search strategy was to locate failed companies. A primary source used to identify failed companies were career histories of senior managers, which often listed previous jobs in failed biotechnology companies. Additional companies were also located through a number of old directories newspaper articles found through internet searches (see e.g. San Diego Union Tribune, 2003). Information on companies was found using searches for Securities and Exchange Commission (SEC) filings, archived company web-pages, and newspaper articles about the company founded through Lexis-Nexus and Internet searches. This research yielded 155 biotechnology companies which had failed or more commonly had been acquired.

Table 1 summarizes information on companies located as part of the study on a yearly basis from 1976 to 2005. These figures demonstrate that San Francisco and San Diego have developed sizable biotechnology clusters. The two regions have spawned a similar number of companies (208 for San Francisco and 207 for San Diego), and an equal number of companies, 68 per region, have achieved the significant milestone of achieving a successful initial public offering onto a stock market. Los Angeles has only generated 32 biotechnology companies. Two of these companies, Allergan and ICN Pharmaceuticals, are local pharmaceutical companies that took stock market listings during the 1970s and moved into biotechnology during the 1980s and 1990s. Excluding these two firms, only one Los Angeles biotechnology company, Amgen, has achieved an initial public offering, in 1983. Due to its lower failure rate the San Francisco cluster has had a larger number of active firms most years, compared to San Diego. Moreover, the data on senior management teams discussed below indicate that its companies are larger, in terms of employment.

--- Table 1 about here ---

Gathering senior manager career histories

Career histories were gathered for all individuals identified as occupying a senior management position in a California biotechnology company. Career histories were first gathered for senior managers active in California biotechnology firms at the time of data collection, between the Summer of 2006 and Summer 2007. Career histories for these individuals were identified through accessing company web sites, SEC filings, and Google Searches, which often yielded press releases announcing career moves of individuals. Much of the data collecting for this project surrounded identifying individuals that exited the network prior to 2005. Many individuals retired, moved to roles outside of regional biotechnology firms, such as becoming a venture capitalist, or had moved to a company outside California.

Several strategies were used to locate such individuals that had exited the California industry. First, for the 137 public companies, SEC filings were used to catalog senior manager biographies using each company's IPO prospectus and subsequent annual reports. SEC filings were the most reliable source of career history data, as SEC rules mandate that companies provide career details for senior managers going back at least five years; in practice most individuals provide complete career data. Second, a public web-archive was used to access historical web-pages for all companies in the database that had web-pages from 1996. This database was particularly useful in gathering information for most privately held companies active for at least part of their history after 1996 (a small number of companies have blocked access to old-web pages). Once names of senior managers were gathered from archived web-sites, internet searches were used to fill in career histories for senior managers located.

While this search strategy yielded career histories for a large number of senior managers active within California biotechnology, there are sources of missing data that could bias the results. For some individuals it was not possible to obtain accurate dates of employment for all jobs. As a key goal of the project was to construct the emergence of career affiliation networks on a yearly basis, all jobs for which dates were not known were dropped from the database. In practice, most missing dates surrounded scientific training or non-biotech related jobs. Once a person moved into the biotechnology industry web-searches, especially using the web-archive, were able to locate dates of employment. Second, data is missing for private companies for which no archived web-page material is available. This includes a small number of private companies that have blocked access to their historical web page, but, more importantly, all private companies active prior to the widespread adoption of internet web-sites in the mid 1990s.

The issue of missing data during the early history of the cluster is significant, as a major goal of this study is trace mechanisms of social network emergence during those early years. Missing data could result in important ties linking senior managers from early companies being excluded from the data, suggesting that less connectivity exists within the network than is actually the case. To help minimize the impact of bias, a variety of secondary sources were used to supplement the social network analysis. Chief among these are a collection of oral histories documenting the early history of biotechnology in California (Bancroft Library 2009). These histories include two over a dozen extended interviews surrounding the formation of Genentech and Chiron in San Francisco, but also detailed accounts of the emergence of Amgen in Los Angeles and Hybritech in San Diego. Several newspaper articles on the history of San Diego biotechnology were used to verify information on the role of Hybritech on the cluster's formation. Finally, in order to highlight differences in the organization of pre-existing infrastructures supporting new technology firms across San Diego and San Francisco, data on the identify of early stage venture capital investors was gathered from the VentureExpert web-site.

Social network construction and summary data on social structure

A databqase was used to generate career affiliation networks. Ties between individuals are created through joint employment within the same organization. Under this rule of tie formation, ties linking individuals across organizations are only formed through job mobility. Upon changing jobs a manager maintains ties with members of the old organization, while creating new ties at the new place of employment. While entire careers were captured for most senior managers, individuals are included in network files starting the year they begin working for a California biotechnology firm, and are removed from networks when they move to either a job outside the California biotechnology industry or move to a job outside the state. Networks were created for each year between 1976 and 2005. The yearly network data allows detailed process tracing as to the formation of the network.

An important issue surrounding the construction of networks is how long ties should be assumed to last once an individual leaves an organization. Once an individual moves jobs there is a probability that ties will decay, or weaken over time as people lose contact with one another. Moreover, and from a network modelling perspective, if ties are assumed to last indefinitely, dense social networks become much easier to produce and become sustainable. By creating a model where ties decay, new ties must be continuously generated in order for a network to become sustainable. Following an approach implemented in network emergence studies by Uzzi and Spiro (2004) and Fleming et al. (2004), the study assumes that ties linking an individual to others within an organization cease to exist *five years* after an individual changes jobs, unless renewed by subsequent joint employment at the same organization. As ties linking organizations are only produced through mobility, factoring tie decay generates a system in which relatively high levels of labor market mobility will be needed to maintain dense social networks.

Table 2 summarizes data on the number of senior managers identified as well as descriptive statistics on social network formation for each region. The data on individuals in the network shows that a significant number of senior managers worked in California biotechnology between 1976 and 2005. At the end of the study's time frame

2285 senior managers were employed in California biotechnology firms. Over half these individuals, 1229 were employed in San Francisco, with 867 employed in San Diego and a much smaller number, 199, employed in Los Angeles. These results mirror the earlier data on the number of companies, demonstrating that San Francisco and San Diego have developed significant labor market pools for senior biotechnology managers, while Los Angeles has not.

-- Table 2 about here --

Table 2 also includes summary data on social network formation within each of the three regions. Within table 2 the data on individuals in the main component and percent in the mail component relate to the connectivity within the network over time. The main component refers to the largest group of individuals within the network that are connected to one another by career affiliation ties. From the 1990s onwards both San Diego and San Francisco have relatively large main components in which at least 80% of individuals are connected to one another; from the mid-1990s onwards network connectivity increases to over 90%. Moreover, the size of the main component becomes relatively large. This is especially true during the latter years of the network history, when over 1000 individuals are connected within the San Francisco network, and over 800 in San Diego. This data provides support that the two successful biotechnology clusters in California, San Francisco and San Diego, both share a network of social ties linking senior managers of most companies.

Los Angeles, on the other hand, has failed to generate significant social ties linking companies. During the 1990s onwards only about 35% of individuals on average are connected to one another through the main component. Moreover, for most years the majority of these individuals are senior managers at Amgen, a very large biotechnology firm. This data shows suggests that very few individuals employed within Los Angeles biotechnology firms have changed jobs to another biotechnology firm in the region. Moreover, when people did leave Los Angeles biotechnology firms, they usually moved to jobs outside of the region, or left biotechnology, when doing so. Between 1981 (the year Amgen was formed) and 2005 there were 170 instances of individuals leaving jobs at Los Angeles biotechnology firms. In only 21 cases (12% of moves) did people relocate to other LA biotech firms. This compares, for example, to 343 lateral career moves within San Francisco biotechnology. While San Francisco and San Diego may have developed patterns of high career mobility across their firms needed to generate a decentralized social structure, Los Angeles has not.

If San Francisco and San Diego have in fact developed decentralized social structures, individuals should be able to readily access network ties as conduits to gather information and as a source of referral networks for jobs. Network statistics can examining whether the structure of the network, as it evolves over time, becomes efficient in developing ties between senior managers and other companies. How easy is it, on average, for members of the network to develop ties to other individuals and firms in any given year? Referrals are often developed by "working the network" or asking acquaintances for contacts that may know at target companies. A common statistic to measure indirect ties is average path length, or "degrees of separation," between individuals in the network.

The final columns of table 2 displays path length between individuals located within the network main component on a yearly basis. The Los Angeles findings are somewhat meaningless, as low path lengths are driven by the small size of the main component during most years. Focusing again on San Francisco and San Diego, during the early history of the region path length data is low in both regions, at less than 2 ties. This is due to the small size of the network. However, from 1990 onwards the average path length averages at about 3.5 to 4 in San Diego and 3 to 3.5 in San Francisco. The stability in the average path length statistic in both regions is impressive given the rapid growth of the size of the social network linking individuals. This is particularly striking in the San Francisco area. In 2005, for example, an individual located within the network main component could reach, on average, any one of the other 1120 through an average of 3.4 referral ties. Hundreds of individuals, and dozens of companies, are reachable to individuals within this network at one to two degrees of separation.

Patterns of network emergence within California biotechnology

The San Francisco and San Diego regions have generated large biotechnology clusters and dense career affiliation networks that are indicative of decentralized social structures. Drawing on the institutional and constructivist approaches outlined earlier, the following examines in more detail the trajectories of social network emergence within these two regions.

San Francisco Bay Area: inheriting biotechnology from Silicon Valley

Recent research on the origins of biotechnology have stressed the importance of San Francisco as a hub of interdisciplinary molecular biology and genetics research (see e.g. Jong 2006). A 1973 collaboration between Stanley Cohen of Stanford and Robert Boyer of UCSF lead to the first successful use of restriction enzymes and plasmids to successfully splice a gene from one organism into another. A few years later, the William Rutter and Howard Goodman labs at UCSF collaborated to successfully "clone" the gene responsible for expressing the insulin protein in rats and then successfully splice it into the e-coli bacteria. Shortly thereafter, in August 1978 the Boyer Lab at UCSF, financed by Genentech, led the collaboration to repeat this experiment using the human insulin gene, but with synthetically manufactured DNA (see Hall 1987). Several prominent scientists in the region, including Boyer, Rutter, and Arthur Korberg from Stanford, would found early biotechnology companies, which would then employ key junior scientists from their labs to carry forward research. There can be no doubt that the founding of San Francisco's early biotechnology firms, such as Genentech, Chiron and DNAX, must be linked to the invention of basic genetic engineering tools within these firms founding academic labs (Kenney 1986).

According to this logic, San Francisco was first to have a biotechnology industry due to the excellence of its science. The implication of this explanation is that the regions experiencing early success in biotechnology did so because they were co-located with prominent labs active in the academic biotechnology revolution. However, this does not necessarily imply that regions that developed early firms within the history of the industry would go on to develop large regional clusters. In a study of the biotechnology industry's formation, Romanelli and Feldman (2006) show that Dallas, Durham, Philadelphia, Washington DC, and Albuquerque joined San Francisco, San Diego, and Boston in housing at least one biotechnology firm prior to 1980. However, only the latter three regions developed sizable biotechnology clusters. It does not necessarily hold true that the early formation of one or more biotechnology firms creates an advantage leading to the broader development of a regional cluster.

The San Francisco region was able to rapidly develop a sizable biotechnology industry, housing 7 firms in 1980, 22 firms in 1985, and 49 firms in 1990. The explanation offered here focuses more on institutional factors. The San Francisco Bay area biotechnology industry expanded as quickly as it did because it inherited the institutional infrastructure created during the 1960s and 1970s within the Silicon Valley semiconductor and computer industries. Genentech provided a powerful demonstration effect of the promise of biotechnology. As numerous academic labs were active in genetic engineering and related molecular biology fields linked to biotechnology, it is not surprising that numerous follow-on biotechnology companies developed. However, Silicon Valley had a pre-existing social structure supporting high-tech entrepreneurialism, carried forward within the region by a cadre of successful entrepreneurs and, of central importance to early biotechnology firms, a large and successful venture capital industry. Evidence from this paper's study of social network emergence within the region as well as supplemental data on the activities of venture capitalists in funding Bay Area biotechnology companies support this explanation.

Data from table 2 shows that San Francisco companies were able to recruit significantly more senior managers to join individual firms compared to San Diego. While this true over the entire history of both clusters, this finding is particularly important during the formative years of biotechnology. Thus, in 1980 while San Diego firms employed only 7 senior managers (most of which were involved with Hybritech), San Francisco firms had 41. By 1983 this disparity reached 104 to 27, and 149 to 47 in 1985. San Francisco biotechnology firms were able to attract dozens of senior managers, this at an early stage in the industry when only Genentech had demonstrated success and no firm had achieved profitability. This evidence is consistent with the explanation that a social structure encouraging mobility into high-risk firms was established within the region's emerging biotechnology industry at the time of its formation.

A key element of narratives accounting for the success of the Silicon Valley semiconductor and computer industry is the willingness of individuals to found new companies. Drawing on the widely known history of the founding of Fairfield Semiconductors by the "traitorous eight" engineers from Shockley Semiconductors in 1957 (see Lécuyer 2006), Silicon Valley is rife with instances of senior employees leaving their firm to found rival companies. Evidence suggests that norms favoring the founding of companies have spread to the Bay Area biotechnology industry. Table 3 draws from the database on the founders of California biotechnology firms to examine the number of founders in each region as well as the frequency of serial foundings. This table shows that the San Francisco area has the most individual biotechnology founders, at 269, compared to 179 in San Diego and 106 in Los Angeles. However, San Francisco biotechnology company founders have a much higher frequency of becoming serial entrepreneurs: 128 individuals, close to half of all founders, have started two or more companies. Eleven individuals have founded 5 or more companies in San Francisco. This compares to a rate of only 25% of individuals becoming serial founders in San Diego, and 20% in Los Angeles. Indeed, San Francisco has more serial founders in biotechnology than Los Angeles has founders. This difference in entrepreneurialism supports the notion that social norms in San Francisco strongly encourage the founding of companies – even if this means leaving a successful enterprise to do so.

--- table 3 about here ---

A decentralized social structure encouraging the formation and employment within biotech firms existed early on in San Francisco biotechnology. But by what mechanisms did these norms become embedded within the new industry? The career history database shows that no senior managers employed within San Francisco biotechnology firms during the 1976-1985 period had worked in a Bay Area semiconductor or computer firm. Most early senior managers employed with San Francisco biotechnology firms had previous careers in academic science or were recruited into the Bay Area from chemical or pharmaceutical companies outside the region and were thus novice employees of high-technology start-ups. Most managers working within early San Francisco companies apparently did not bring such norms into firms through earlier career experiences within the region. It is possible that norms encouraging social ties across firms and frequent mobility were "in the air" and may have been transferred to local companies through informal social interaction with other entrepreneurs and high-technology employees active in the area. However, a more direct explanation lies with the organization of most of the area's early biotechnology firms by local venture capitalists.

The venture capital firm Kleiner Perkins is well-known for its role in backing Cetus in 1973 and then Genentech in 1976 (see Hall 1987). Kleiner Perkins adopted strategies of allocating capital to Genentech in several allotments that increased in size over time as the company achieved technical milestones leading, eventually, to its initial public offering in 1980. Kleiner Perkins also asserted strong control of the firm through organizing Genentech's Board of Directors. Both tactics were imported directly from common venture capital tactics used in the semiconductor and computer industries. However, Kleiner Perkins was not otherwise active in funding San Francisco biotechnology firms. After funding several rounds of Genentech's development in the late 1970s the company would not invest in another Bay Area biotechnology firm until 1987, when it invested in Penederm. In terms of directly funding firms, Kleiner Perkins was far more active in the San Diego area, as will be discussed shortly.

Kleiner Perkin's success with Genentech did, however, play an important demonstration effect within the Bay Area. Between 1976 and 1985 twenty Bay Area venture capitalists would become active in funding San Francisco based biotechnology firms. Twenty six biotechnology start-ups were founded during this period, implying that most VCs invested in one, or possibly two biotechnology firms. This suggests that most early venture capital investors into biotechnology were conservative, investing in one biotech or at most two biotechnology firms to gain a foothold in this new industry, but also limiting their investment exposure to this industry given its high technological risk and unproven business models. From this perspective, the existence of a large venture capital industry in San Francisco helps directly explain why the region was first to develop a significant number of biotechnology firms. San Francisco had more venture capital companies, and thus could support more start-ups.

As with Kleiner Perkins, most early venture capital investors into San Francisco firms had prior experience primarily in funding semiconductor and computer firms. The strategies used by Kleiner Perkins in financing Genentech would be adopted by almost all other Bay Area biotechnology firms and, within a few years, become the standard template for organizing biotechnology firms across the world. As Pisano (2006) has recently argued, the "anatomy" by which biotechnology firms have been organized and funded draws from venture financing in the electronics industry. However, within San Francisco VC investors also are likely to have imprinted broader elements of the "Silicon Valley model" into area companies. As venture capitalists began to organize biotechnology firms in the region, it is likely that they imprinted patterns of financing and organizing new technology that were borrowed from norms established within the semiconductor and computer industry. This included norms of high career mobility across companies and a willingness for key employees to leave companies to become entrepreneurs active in founding other companies. The development of frequent job hopping within the San Francisco biotechnology industry followed, allowing the region to develop the social networks needed to support a decentralized social structure.

San Diego biotechnology: construction of a network backbone

While the biotechnology firms in San Francisco may be considered fortunate in inheriting both a social structure and underlying venture financing industry that were well-suited for the industry, biotechnology entrepreneurs in San Diego had to construct its regional infrastructure. As seen in table 1, the region went from having virtually no presence in commercial biotechnology at the start of the 1980s to developing one of the world's most vibrant biotechnology clusters by the late 1990s (see also DeVol et. al. 2005). While San Diego has recently developed a cluster of wireless telecom companies to complement its biotechnology presence (see Simard 2004), the region did not have a presence in high technology industry during the late 1970s, and was primarily known for its large naval base and defense contractors. This suggests that its biotechnology sector was the first high-technology industry to develop in the region, with the implication that early companies could not draw on previously established local venture capitalists, labor market pools, or other resources.

Given the more organic pattern of cluster emergence in San Diego, a key issue to investigate is whether a mechanism developed to overcome collective action problems surrounding the early growth of flexible labor markets. Through coupling network analysis with a closer analysis of history of the cluster's key firms it is possible to examine the mechanisms by which the network emerged. This leads to a narrative surrounding a network backbone. An interesting finding in San Diego is that a network backbone did develop, and can be attributed almost entirely to the career strategies of a set senior managers with ties to Hybritech, a prominent early San Diego biotech company. A parallel analytic narrative, also strongly linked to Hybritech, surrounds the development of a significant venture capital industry in the region.

While a small number of biotechnology companies existed in San Diego by the early 1980s, only Hybritech was launched by a world class team of venture capitalists, scientific founders, and general managers. Hybritech was founded in late 1978. The company commercialized technology developed at UCSD by Ivor Royston and Howard Birndorf. Hybritech received immediate credibility due to its ability to attract funding from Kleiner Perkins. The VC firm had recently hired Brooks Byers as venture capitalists specializing in biotechnology. Byers assumed responsibility for the initial organization and business direction of Hybritech and became the firm's interim CEO. Byers went on to recruit an experienced management team, lead by Howard Greene, one of several up and coming young general managers who left the medical device firm Baxter to accept leadership positions within the first generation of US biotechnology start-ups (Higgins 2005). During the early 1980s, Hybritech developed a range of diagnostic tests drawing on monoclonal antibody technology. Because these tests did not require a significant regulatory approval process, they could be marketed within months of their invention.

Hybritech thus became one of the few biotechnology firms to achieve profitability early in its existence, and successfully completed an IPO in 1981. While an important early biotechnology firm, Hybritech has become much more famous for its role in “seeding” biotechnology in San Diego. After its IPO the two scientific founders of Hybritech, became interested in founding additional companies. While staying involved with Hybritech, in 1983 Royston and Birndorf helped launch Gen-Probe, another molecular diagnostics company drawing on technology developed at UCSD and Hybritech. The lead venture capital investor in Gen-Probe was again Kleiner Perkins. In 1985 a second spin-out called IDEC was launched by Royston and Birndorf. The company applied Hybritech monoclonal antibody technology to conduct drug discovery research. IDEC was again initially funded primarily through Kleiner Perkins, with Birndorf becoming CEO. IDEC eventually became arguably San Diego’s most successful biotechnology company, developing an important cancer therapy, Rituxan.

In 1986 Hybritech was acquired by the large pharmaceutical firm Lilly for $300 million plus about $100 million Lilly shares (Crabtree 2003). This acquisition had the immediate effect of transforming Hybritech’s top management team, all of whom owned shares in the company, into extremely wealthy individuals. As part of the acquisition, the top management team was encouraged to remain, but Hybritech became a subsidiary of a large Indiana based pharmaceutical company with a relatively conservative managerial ethos. Hybritech had developed a free-flowing, informal corporate culture typical of technology start-ups. This created immediate clashes with the Lilly managers. Tina Nova, one of the senior scientists at Hybritech, reflects that “It was like ‘Animal House’ meets ‘The Waltons.’” (Fikes, 1999). Lilly was unable to integrate Hybritech’s management and scientific team into its corporate culture, and in the years immediately following the acquisition most of the former Hybritech senior managers left the firm.

The cadre of former Hybritech managers are now widely credited within San Diego for “seeding” the San Diego biotechnology industry. This group of managers could serve as a reliable and trusted referral network to one another. These managers had the financial resources, managerial experience, and a reputation for developing one of the biotechnology industry’s early and rare success stories. Their credibility as successful biotech entrepreneurs was also important in recruiting highly skilled individuals to join San Diego start-ups to which the Hybritech managers were linked. Managers from Hybritech went on to found or take senior management position in at least twelve companies formed between 1986 and 1990. A study conducted in 2002 found over 40 biotechnology companies in San Diego employing a senior manager or board advisor linked to Hybritech (UCSD Connect, 2002).

In addition to helping to form new companies, the former Hybritech managers were instrumental in the creation of a local venture capital industry in San Diego. Prior to 1986 most (of the few) companies founded in San Diego drew on venture capitalists from outside the region, predominately from Silicon Valley. Kleiner Perkins played an especially important role in funding San Diego companies. In addition to its earlier investments in Hybritech, Gen-Probe, and IDEC, between 1986 and 1990 the firm went on to fund several new companies linked to Royston and Birndorf and drawing from ex-Hybritech managers. These include Ligand, Gensia, Genta, and Nanogen. Birndorf developed a reputation with local venture capitalists as an excellent CEO of early stage biotechnology companies, and became initial CEO Ligand, Gensia, and Nanogen, where he remained for several years. Royston eventually became a venture capitalist, founding Forward Ventures, which became a prominent San Diego venture capital company during the 1990s.

In addition to the companies linked to Kleiner Perkins and the scientific founders of Hybritech, a second clique of companies was started during the 1986-1990 period by a group of managers linked to Howard Greene, the former CEO of Hybritech. Greene had recruited several other former Baxter colleagues to Hybritech. After leaving Hybritech Grene co-founded with Tim Wollaeger, another former Baxter executive from Hybritech, a short-lived venture capital seed investment company called Biovest. Biovest proceeded to invest in six San Diego biotech start-ups, most founded or managed by former Hybritech employees. The Biovest partners concluded their partnership by each founding a new company. Greene founded and became long-term CEO of Amylin, which eventually became a company focused on the development of insulin drugs and eventually grew into a large publicly traded firm. Wollaeger founded Biosite, another molecular diagnostics company. In 1993 Wollaeger left Biosite to become a full-time venture capitalist, opening the San Diego office of Kingsbury Partners.

In addition to founding numerous companies, a credible social network backbone was forged around the former Hybritech managers. Network visualizations, shown in figures 1, can help document this process (see Casper 2007a for additional network visualization analysis of San Diego biotechnology). Within these figures the dots or nodes represent senior managers, and the edges between them represent ties. To simplify the network figures, individuals with no ties to other people within the network (so-called isolates) were removed from the analysis. Managers with career affiliations to Hybritech are colored black, while all other individuals are shaded gray. The visualization from 1984 shows that while a few biotechnology firms existed within San Diego, there were no career affiliation network ties linking any firm except Gen-Probe, the Hybritech spin-out. By 1987, the development of new firms founded primarily by ex-Hybritech managers was well-underway. While fragile, a coherent network linking many of the region's firms now exists. By 1995 a robust network has formed linking a large number of companies. All ties to Hybritech had decayed from the network, and, while most former Hybritech managers were still active within the biotechnology community, their central role in holding the network together appears to have declined. Labor market mobility within the region was sufficient to create sustainable career affiliation networks linking most firms in the region.

--- figures 1 about here (attached) ---

The mechanism of network emergence surrounding the failed Hybritech acquisition helps justify the claim that dynamics surrounding the formation of an appropriate social structure within the region were important in explaining the success of San Diego in developing a large cluster of companies. Through both seeding a generation of follow-on companies and creating a web of social ties across the new firms, the clique of managers linked to Hybritech helped establish a decentralized social structure capable of supporting a robust biotechnology cluster emerged.

Conclusion

This study helped identify mechanisms by which social networks linked to career mobility emerged and became sustainable across California's biotechnology industry. Drawing on research from economic sociology, the article has linked the development of large, sustainable biotechnology clusters to the creation of a decentralized social infrastructure supporting individuals and companies within the region. Empirical studies have demonstrated that large technology clusters only rarely emerge. In this respect, one contribution of this study is to document the existence of decentralized social structures in two successful biotechnology clusters, San Francisco and San Diego. The empirical results also demonstrate a correlation between the failure of Los Angeles to develop a large biotechnology industry and the lack of career affiliation networks linking companies within the region.

Insights from social theory can help conceptualize scenarios of social structure emergence, which were then used to create analytic narratives helping to explore the emergence of successful biotechnology clusters in San Francisco and San Diego. Drawing on institutional theory, it was argued that San Francisco biotechnology developed rapidly because the region's firms inherited a suitable social structure from Silicon Valley. One issue needing more exploration is the identification of precise mechanisms by which norms associated with the Silicon Valley electronics industry were transferred into the newly emerging biotechnology industry. A likely suspect, however, is that the area's venture capitalists were carriers of such norms. More generally, the existence of a large venture capital industry in San Francisco willing to invest in unproven biotechnology firms helps explain why San Francisco was able to quickly obtain a critical mass in the new industry.

One implication of the inheritance scenario is that, once a region succeeds in developing one high-technology industry, it may be able to leverage this success to develop additional high-technology industries that draw upon similar social structure supports. Silicon Valley is known for creating several new technology industries, ranging from first electronics and biotechnology to software, internet technologies, and more recently nanotechnology and biofuels. San Diego, after experiencing success in biotechnology in the mid-1980s San Diego was able to soon after develop an important wireless telecommunications industry. While an attractive scenario, a region must no doubt have adequate factor conditions to support spin-outs in the new industry. Simard (2004), for example, has shown that San Diego's wireless telecommunications industry drew on signal processing technologies developed through governmental research in the area sponsored by the Navy. Nevertheless, if social structures do prove fungible across sectors, this provides a strong justification for the support of policies promoting new technology development within existing technology clusters.

Entrepreneurs contemplating the creation of new technology firms in most regions, however, have little to inherit. Research suggests that very few regional technology clusters have developed decentralized social structures. If so, then actors within most regions must construct the social infrastructure. The failure of biotechnology in Los Angeles demonstrates that promising starting conditions (a leading early firm, Amgen, and strong university research) will not necessarily lead to the formation of social networks supporting further development spirals. Further research into "failure case" such as Los Angeles is needed to help understand why the success of companies such as Amgen did not lead to the types of labor market mobility or social network formation found in nearby San Diego or San Francisco.

The San Diego biotechnology case, however, does show that decentralized social structures can emerge. The failure of Lilly's acquisition of Hybritech lead to the establishment of a viable social network backbone supporting San Diego biotechnology from the late 1980s onwards. The development of this backbone was orchestrated through the activities of social cliques linked to the scientific founders of Hybritech and Kleiner Perkins, on one hand, and the group of former Baxter employees linked through Hybritech, on the other. The emergence of San Diego biotechnology demonstrates how a region can start with a minimal infrastructure for biotechnology and, a few years later, emerge as a leading center of excellence in the field. But in a larger sense the sequence of events surrounding the failed acquisition Hybritech was idiosyncratic and in no sense planned.

Governments around the world are busy orchestrating the development of technology clusters. Due to the centrality of university research in the formation of biotechnology, this sector is a chosen target for governments. A primary strategy used by governments, particularly in Europe, is to use financial instruments to seed the development of numerous early entrants within a regional cluster (see Casper 2007b). While this strategy may create a critical mass of firm, it all bur ignores the social context of successful biotechnology clusters. This article privileged shared career experiences as the source of key social ties that, over time, can catalyze the development of a viable regional social structure. Can government policies orchestrate the development of such entrepreneurial networks? Exploring this issue is an important question for future research on the development of technology industries.

References

Almeida, P. and B. Kogut, 1999. "Localization of Knowledge and the Mobility of Engineers in Regional Networks". *Management Science* 45, 905-917.

Bancroft Library (2009) "Program in Bisocience and Biotechnology Studies Oral History eLibrary". http://bancroft.berkeley.edu/ROHO/projects/biosci/oh_list.html

Baron, James N. and Michael T. Hannan. 2002. "Organizational blueprints for success in high-tech start-ups: Lessons from the Stanford Project on Emerging Companies." *California Management Review* 44, 8-36..

Bahrami, H. and S. Evans, 1999. "Flexible Re-cycling and High-Technology Entrepreneurship." *California Management Review* 37, 62-88.

Berger, P. and T. Luckmann, 1967: *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*. New York: Anchor

Biotech Career Center, 2005. Biotech Graveyard URL: http://www.biotechcareercenter.com/Graveyard_index.html

Braunerhjelm, P. and M. Feldman, 2006. *Cluster Genesis: The Origins and Emergence of Technology-based Economic Development*. Oxford: Oxford University Press.

Casper, S. 2007a. How do technology clusters emerge and become sustainable? Social network formation and inter-firm mobility within the San Diego biotechnology cluster. *Research Policy* 36: 438-455.

Casper, S. 2007b *Creating Silicon Valley in Europe: Public Policy Towards New Technology Industries*. Oxford: Oxford University Press.

Crabtree, P., 1993. "A Magical Place". *San Diego Union Tribune,* September 14.

DeVol, P., J. Ki, A. Bedroussian and R. Koepp, 2005. *America's Biotech and Life Science Clusters: San Diego's Position and Economic Contributions*. Los Angeles: Milken Institute.

Romanelli, E. And M. Feldman, 2006. "Anatomy of Cluster Development: The Case of U.S. Human Biotherapeutics, 1976-2003", in P. Braunerhjelm, and M. Feldman, ed. 2006. *Cluster Genesis: The Origins and Emergence of Technology-based Economic Development*. Oxford: Oxford University Press.

Fikes, B., 1999. "Why San Diego Has Biotech," *San Diego Metropolitan.* http://www.sandiegometro.com/1999/apr/biotech.html

Fleming, L., C. King and A. Juda,. 2004, "Small Worlds and Innovation" Working Paper, Harvard Business School.

Freeman, C. and L. Soete, 1997. *The Economics of Industrial Innovation,* (3rd Edition), London: Pinter Publishing.

Gilson, R., 1999. "The Legal Infrastructure of High Technology Industrial Districts: Silicon Valley, Route 128, and Covenants not to Compete." *New York University Law Review* 74, 3.

Granovetter, M., 1973. "The Strength of Weak Ties." *American Journal of Sociology*, Vol. 78 May.

Hall, S., 1987. *Invisible Frontiers: The Race to Synthesize a Human Gene*. New York: Atlantic Monthly Press.

Herrigel, G., 1993. Power and the Redefinition of Industrial Districts: The Case of Baden-Württemberg, in Grabher, G. ed., *The Embedded Firm*, London: Routledge.

Higgins , M., 2005. *Career Imprints: Creating Leaders Across an Industry*. New York: Wiley and Sons.

Higgins, M. and Gulati, R., 2003. "Getting Off to a Good Start: The Effects of Upper Echelon Affiliations on Interorganizational Endorsements." *Organization Science*, 14, 244-263.

Kenney, M., ed., 2000, *Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region*. Palo Alto: Stanford University Press.

Kenney M., 1986. *Biotechnology: The University-Industrial Complex*. New Haven: Yale University Press.

Kenney, M. and R. Florida, 1998. "Venture-capital financed innovation and technological change in the USA." *Research Policy* 17: 119-139

Kogut, B., P. Urso, and G. Walker, 2007. "The Emergence of a New Financial Market: American Venture Capital Syndication from 1960 to 2000." *Management Science* 53: 1181-1198.

Gilson, R. 1999. "The Legal Infrastructure of High-Technology Industrial Districts: Silicon Valley, Route 128, and Covenants Not to Compete." *New York University Law Review* 575: 594-619.

Lerner, J. and P. Gompers, (2001). *The Money of Invention: How Venture Capital Creates New Wealth.*, Cambridge: Harvard Business School Press.

Hyde, A. 1998. "Employment law after the death of employment." *University of Pennsyvania Journal of Labor Law* 1: 105-120

Henderson, R., L. Orsenigo, and G. Pisano, 1999. “The Pharmaceutical Industry and the Revolution in Molecular Biology: Interactions Among Scientific, Institutional and Organizational Change.” In David Mowery and Richard Nelson, ed. *Sources of Industrial Leadership* Cambridge: Cambridge University Press, pp. 267-311.

Lécuyer, C. (2006). *Making Silicon Valley: Innovation and the Growth of High Tech, 1930–1970* Cambirdge: MIT Press.

Mowery, D., R. Nelson, B. Sampat, and A. Ziedonis, 2004, *Ivory Tower and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act in the United State*s. Palo Alto: Stanford University Press.

Murray, F., 2004. ”The Role of Inventors in Knowledge Transfer: Sharing in the Laboratory Life.” *Research Policy,* Vol 33, 643-659.

Penan, H., 1996. “R&D Strategy in a Techno-Economic Network: Alzheimer’s Disease Therapeutic Strategies.” *Research Policy* 25, 337-358.

Owen-Smith, J. and W. Powell, 2004. “Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community.” *Organization Science* 51, 5-21.

Powell, W., 1998, “Learning from Collaboration: Knowledge and Networks in the Biotechnology and Pharmaceutical Industries.” *California Management Review* 40, 228-40

Powell. W., Koput, K., Smith-Doerr, L., 1996. “Inter-organizational Collaboration and the locus of Innovation: Networks of learning in Biotechnology.” *Administrative Science Quarterly* 41, 116-145.

Ruggie, J. 1998. “What makes the world hang together? Neo-utilitarianism and the social constructivist challenge.” *International Organization* 52: 855-885.

Sabel, C., 1992. “Studied Trust: Building New Forms of Cooperation in a Volatile Economy.” Pp. 104-44 in *Explorations in Economic Sociology,* edited by R. Swedberg. New York: Russell Sage Foundation.

Saxenian, A., 1994, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, Ma: Harvard University Press

Simard, C., 2004, “From Weapons to Cell Phones: Knowledge Networks in San Diego’s Wireless Valley.” Dissertation, Stanford University.

Shan, W., G. Walker and B. Kogut,1994. “Interfirm cooperation and startup innovation in the biotechnology industry.” *Strategic Management Journal*, 155: 387-394.

Storper, M., 1997. *The Regional World*. New York: The Guilford Press

Uzzi, B. and J. Spiro, 2005. Collaboration and Creativity: The Small World Problem." *American Journal of Sociology* 11: 447-504.

Walker, G., B. Kogut and W. Shan., 1997. "Social Capital, Structural Holes and Formation of an Industry Network." *Organization Science*. 8: 109-125.

Whitley, R., 2006. "Project-based Firms: New organisational form or variations on a theme?" *Industrial and Corporate Change* 15: 77-99.

Zucker, L., Darby, M., Brewer, M., 1998. Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises. American Economic Review 88, 290-306.

Figures and tables:

	Total Firms			Entrants			Exits			IPOs			Public Firms		
	SF	SD	LA	SF	SD	LA	SF	SD	LA	SF	SD	LA	SF	SD	LA
1976	2	0	2	1	0	1	0	0	0	0	0	0	0	0	2
1977	2	0	2	0	0	1	0	0	0	0	0	0	0	0	2
1978	2	1	2	0	1	1	0	0	0	0	0	0	0	0	2
1979	5	2	2	3	1	0	0	0	0	0	0	0	0	0	2
1980	7	2	3	2	0	0	0	0	0	1	0	0	1	0	2
1981	13	4	4	6	2	3	0	0	0	1	1	0	2	1	2
1982	16	8	5	3	4	1	1	0	0	0	0	0	2	1	2
1983	15	10	5	0	2	1	0	0	0	4	1	1	6	2	3
1984	17	14	5	2	4	0	0	0	0	1	0	0	7	2	3
1985	22	17	8	5	3	1	0	1	0	0	1	0	7	3	3
1986	25	22	9	3	6	1	1	1	1	2	1	0	8	3	3
1987	29	31	10	5	10	1	0	0	0	0	3	0	8	6	3
1988	38	38	10	9	7	3	0	1	0	0	1	0	8	7	3
1989	43	45	10	5	7	0	0	0	1	0	1	0	8	8	3
1990	49	47	10	6	2	0	2	3	0	0	1	0	8	9	3
1991	61	52	11	14	8	0	4	0	0	3	8	0	9	17	3
1992	66	61	14	9	9	3	0	1	0	9	5	0	18	22	3
1993	69	65	13	3	5	3	0	1	0	7	3	0	25	25	3
1994	80	70	13	11	6	1	0	4	1	4	1	0	29	24	3
1995	91	75	13	11	9	2	3	2	0	2	4	0	30	27	3
1996	94	83	16	6	10	4	3	2	0	8	6	0	36	33	3
1997	109	97	19	18	16	0	4	5	2	2	6	0	35	36	3
1998	133	116	19	28	23	2	3	6	1	0	1	0	32	34	3
1999	140	120	21	10	11	1	9	3	1	3	1	0	31	34	3
2000	142	142	25	11	26	1	0	8	1	13	10	0	44	39	3
2001	149	147	23	7	13	0	6	9	2	0	2	0	42	38	3
2002	154	147	24	11	9	1	7	4	0	1	1	0	40	37	3
2003	159	150	24	12	8	1	8	9	0	2	2	0	41	36	3
2004	157	144	25	5	1	1	8	4	0	3	4	0	43	40	3
2005	149	142	23	2	4	0	4	9	0	2	4	0	44	40	3
				208	207	31	63	73	10	68	68	1			

Table 1: Company statistics for California biotechnology clusters, 1976-2005

	Individuals in Network			Individuals in Main Component			Percent in Main Component			Average Path Length within Main Component		
	SF	SD	LA	SF	SD	LA	SF	SD	LA	SF	SD	LA
1976	23			13			56.5%			1.3		
1977	24			9			37.5%			1.0		
1978	28	2		12	2		42.9%	100.0%		1.3	1.0	
1979	31	4		11	3		35.5%	75.0%		1.3	1.0	
1980	41	7	14	12	4	9	29.3%	57.1%	64.3%	1.2	1.0	1.0
1981	60	9	18	24	4	11	40.0%	44.4%	61.1%	1.3	1.0	1.0
1982	86	19	20	41	9	12	47.7%	47.4%	60.0%	1.3	1.0	1.0
1983	104	27	28	50	15	17	48.1%	55.6%	60.7%	1.2	1.0	1.2
1984	124	39	33	47	17	18	46.0%	43.6%	54.5%	1.2	1.1	1.0
1985	149	47	37	105	24	18	70.5%	51.1%	48.6%	2.4	1.2	1.0
1986	166	59	44	113	35	19	68.1%	59.3%	43.2%	2.3	1.8	1.0
1987	205	78	47	105	57	20	51.2%	73.1%	42.6%	1.8	2.8	1.0
1988	233	107	51	175	81	21	75.1%	75.7%	41.2%	3.8	3.1	1.0
1989	266	132	58	202	103	24	75.9%	78.0%	41.4%	3.4	3.3	1.0
1990	312	165	64	248	135	25	79.5%	81.8%	39.1%	2.9	3.9	1.0
1991	359	188	67	300	151	26	83.6%	80.3%	38.8%	2.9	3.7	1.0
1992	420	232	75	361	204	29	86.0%	87.9%	38.7%	3.0	3.8	1.0
1993	470	273	78	402	243	29	85.5%	89.0%	37.2%	3.0	4.1	1.0
1994	531	317	83	462	290	30	87.0%	91.5%	36.1%	3.1	4.0	1.0
1995	597	342	99	543	300	35	91.0%	87.7%	35.4%	3.1	3.6	1.0
1996	669	397	108	608	347	38	90.9%	87.4%	35.2%	3.2	3.5	1.1
1997	743	452	119	662	409	37	89.1%	90.5%	31.1%	3.2	3.6	1.1
1998	837	503	126	764	466	36	91.3%	92.6%	28.6%	3.1	3.6	1.1
1999	910	547	133	847	498	72	93.1%	91.0%	54.1%	3.2	3.6	2.0
2000	1004	624	122	944	559	41	94.0%	89.6%	33.6%	3.1	3.8	1.3
2001	1079	702	154	1029	648	56	95.4%	92.3%	36.4%	3.3	3.8	2.0
2002	1134	771	173	1075	719	58	94.8%	93.3%	33.5%	3.2	3.8	2.0
2003	1187	817	186	1117	760	58	94.1%	93.0%	31.2%	3.8	3.8	2.3
2004	1204	852	197	1122	806	86	93.2%	94.6%	43.7%	3.4	3.9	2.4
2005	1229	867	199	1121	824	78	91.2%	95.0%	39.2%	3.4	4.2	2.3

Table 2: Social Network Statistics: Senior Managers Employed within San Francisco, San Diego, and Los Angeles Biotechnology Clusters, 1976-2005

Number of Companies Founded	LA	SD	SF
1	80% (85)	75% (134)	54% (146)
2	12% (13)	19% (34)	26% (69)
3	4% (4)	4.5% (8)	12% (32)
4	2% (2)	1% (2)	4% (11)
5 or more	2% (2)	.5% (1)	4% (11)
Repeat Founders	20% (21)	25% (45)	46% (123)
Total # Founders	106	179	269

Table 3: Company founder frequency across California biotechnology

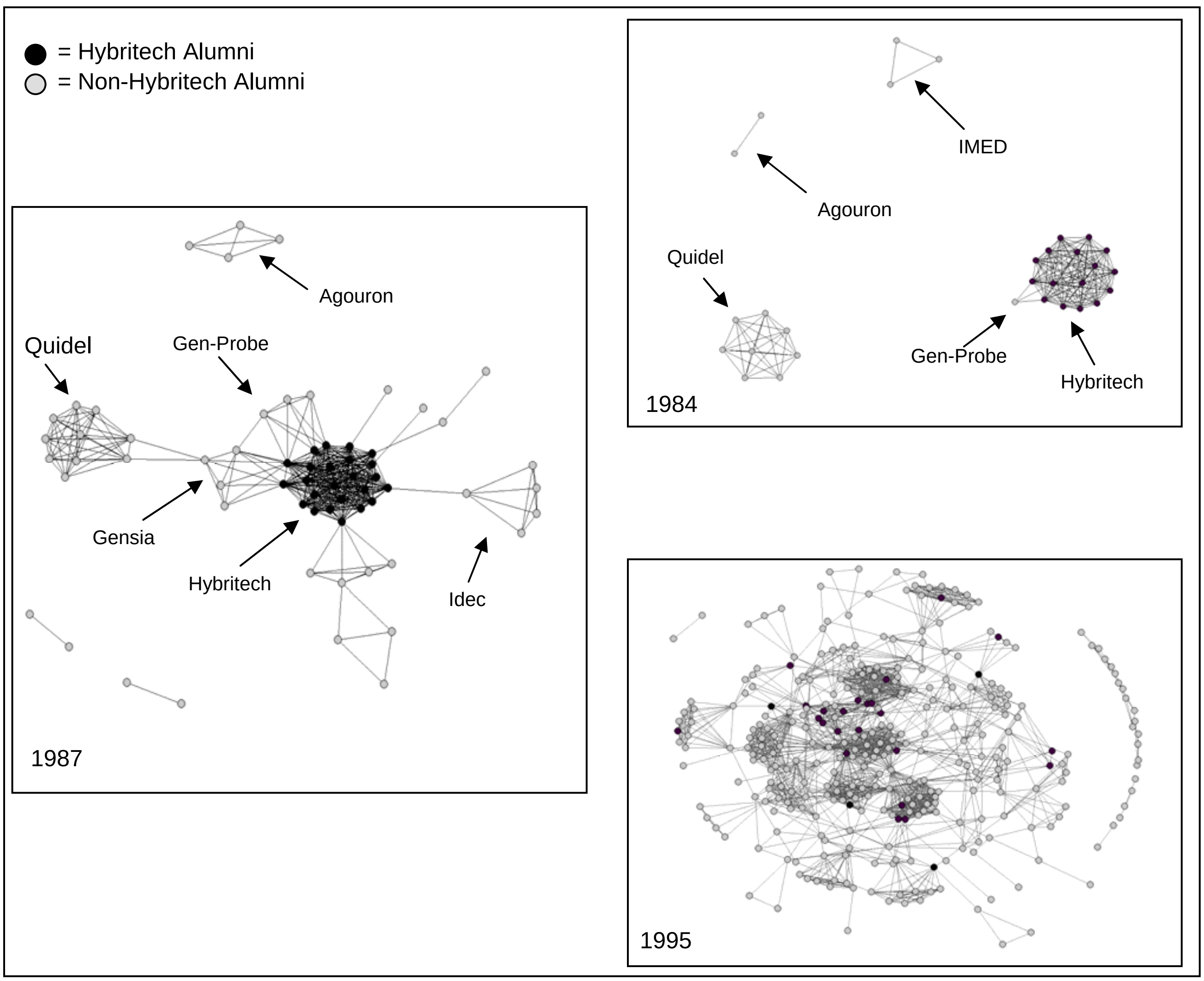

Figure 1: San Diego Career Affiliation Visualizations