SSI

New-technology clusters and public policy: Three perspectives

Social Science Information
52(4) 628–652

DOI: 10.1177/0539018413501236
ssi.sagepub.com

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Abstract

Regional technology clusters are an important source of economic growth within the knowledge economy. The success of Silicon Valley in particular has shown that university discoveries can spill over into regional economies to drive the emergence and growth of major new industries. From a public policy standpoint, the goal of 'creating more Silicon Valleys' has emerged as a major goal of recent technology policy. Evidence suggests that regional clusters focused on high technology only rarely develop. How do regional technology clusters emerge, and what makes them sustainable? A large literature has emerged attempting to answer this question. This article surveys three major perspectives on technology clusters: (1) approaches focused on universities as the anchor of regional clusters; (2) theories focusing on the development of social networks within clusters; and (3) institutional explanations. Each of these three approaches focuses on factors that are unquestionably important in explaining why some regions develop successful clusters while others do not. Each approach also yields a clear policy perspective and has itself influenced public policy. At best, each approach can, however, yield only a partial explanation of cluster success, but in combination they do reveal how complementary the perspectives are. A holistic approach that combines insights from the three approaches yields a reasonably clear understanding of key factors that explain why some regions successfully develop technology clusters while others do not.

Keywords

institutional analysis, public policy, regional technology clusters, Silicon Valley, social networks

Résumé

Les pôles technologiques régionaux sont un facteur important de croissance économique dans nos économies de la connaissance. Le succès de la Silicon Valley

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en particulier a montré que les découvertes faites à l'université peuvent rejaillir sur les économies régionales et piloter à leurs débuts la croissance de nouvelles industries importantes. D'un point de vue de politique publique, la 'création de plus de Silicon Valleys' est récemment apparue comme un enjeu majeur de la politique technologique. Les faits montrent que les pôles régionaux axés sur la haute technologie ne se développent que rarement. Comment les pôles technologiques régionaux se développent-ils, et qu'est ce qui les rend durables? Il existe une abondante littérature dont l'objet est de tenter de répondre à cette question. L'article passe en revue trois grandes perspectives sur les pôles technologiques: (1) les approches qui mettent l'accent sur les universités comme ancrage des pôles régionaux; (2) les théories qui mettent l'accent sur le développement des réseaux sociaux à l'intérieur des pôles; et (3) les explications institutionnelles. Chacune d'entre elles met l'accent sur le développement des facteurs importants qui sont sans aucun doute incontournables pour expliquer pourquoi certaines régions développent des pôles à succès alors que d'autres ne le font pas. Chaque approche produit également une perspective politique claire et toutes trois ont influencé les politiques publiques. Cependant, elles ne peuvent au mieux que fournir une explication partielle du succès d'un pôle et sont par ailleurs complémentaires. Une approche holistique, combinant les perspectives de ces trois approches, permet de comprendre assez clairement quels sont les facteurs décisifs qui peuvent expliquer pourquoi certaines régions réussissent à développer des pôles technologiques à succès, alors que d'autres ne le font pas.

Mots-clés

analyse institutionnelle, politique publique, pôles technologiques régionaux, réseaux sociaux, Silicon Valley

Regional technology clusters, or local agglomerations of firms within a given technology-oriented industry, have been an important driver of economic growth within the knowledge economy. The success of Silicon Valley, in particular, has shown that university discoveries can spill over into regional economies to drive the emergence and growth of major new industries (Kenney, 2000). Semiconductors, personal computers, biotechnology, internet software and telecommunications, and, more recently, the biofuels industry all have developed major clusters of activity in Silicon Valley. From a public policy standpoint, the goal of 'creating more Silicon Valleys' has emerged as a major focus for recent technology policy (see Hage, 2011).

However, evidence suggests that regional clusters focused on high technology only rarely develop (see generally Braunerhjelm & Feldman, 2006; Breschi & Malerba, 2007). In biotechnology, for example, only three major clusters exist: in San Francisco, San Diego, and Boston (see DeVol et al., 2005). While there are dozens of smaller biotechnology clusters around the world, none has been able to match the size, in terms of number of firms or employment, of these three major clusters. In terms of employment, the San Diego cluster is larger than the entire biotechnology industry of the United Kingdom, which has long boasted Europe's strongest biotechnology sector (see Casper, 2007b). In the semiconductor industry, while at least a dozen agglomerations of firms exist in the United States, research has found that the Silicon Valley cluster is exceptional in its ability to nurture large technical communities of engineers (Fleming et al., 2007) and that the region has a much higher innovative output, in terms of patents, than other putative semiconductor clusters in the United States (Almeida & Kogut, 1999).

A large body of literature has emerged in the broad area of regional technology clusters. The goal of this article is to synthesize theoretical perspectives and empirical findings from this literature to help shed light on two important questions: First, how do regional technology clusters emerge, and what makes them sustainable? Second, what is the role of government, if any, in the development of technology clusters?

To explore these questions, this article surveys three major perspectives on technology clusters: (1) approaches focused on universities as the anchor of regional clusters; (2) theories focusing on the development of social networks within clusters; and (3) institutional explanations. While there are overlaps across these perspectives, each focuses on a different constellation of causal factors that are unquestionably important in explaining why some regions develop successful clusters when others do not. Each approach also yields a clear policy perspective that has influenced government policy. We will see that each approach can, at best, yield only a partial explanation of cluster success, but in combination they do reveal how complementary the perspectives are. A holistic approach, combining insights from the three approaches yields a reasonably clear understanding of key factors that explain why some regions successfully develop technology clusters while others do not

While the article aims to provide a useful synthesis of major currents within the academic literature on regional technology clusters, it has important limits. Though there are many types of regional clusters (see Porter, 1998), this article focuses on high-technology clusters, and especially clusters focused on industries in which the creation of small technology-oriented start-up firms has been important. Biotechnology and software are relevant examples, though many new technology industries today employ similar organizational and financing strategies. Moreover, the geographical coverage of the article is focused primarily on North America and Europe, and especially the analysis of biotechnology-related clusters in the United States and Germany, two countries in which the author has conducted extensive primary research on technology clusters. As a result, although the conclusions drawn from the analysis might be limited in scope to the advanced industrial countries, they should be relevant to knowledge-based industries in which access to university science is important.

Universities as the anchors of technology clusters

Universities play an anchor role within many (but not all) technology clusters through generating a labor market of highly trained scientists and engineers within a cluster, and serving as a source of technology that local firms can tap through active collaboration and licensing. Perhaps most importantly, the founding ideas for many new-technology start-ups within clusters originate with university faculty, who frequently work with local entrepreneurs and venture capitalists to found companies. The origins of Silicon Valley, for example, are tightly linked with entrepreneurial activities linked to the Stanford University Engineering Department (Lécuyer, 2005), and early companies in other major technology clusters in the United States have also emerged as university spin-offs. Moreover, the perspective of viewing universities as the anchor of technology clusters has a straightforward public policy implication: government can use their control of universities – either directly in the case of public universities, or indirectly through manipulating rules surrounding the funding of research – as tools of economic development. Within this context, universities have been targeted as 'engines of growth' (Florax, 1992) within economies. Economic development has become a 'third mission' for universities (Etzkowitz, 2002), complementing education and basic research, and frequently used to justify public investments in university research (see Hage, 2011; National Academies, 2007).

The concept of technology spillovers has motivated much research on universities as drivers of regional economic development. While scholars have long viewed basic research as a public good that could spill over into society (Arrow, 1962; Rosenberg & Nelson 1994, 1996), the recognition that knowledge being developed in universities is often tacit or 'sticky' (Von Hippel, 1994) led to a wave of research viewing universities as anchors of regional economic development (see e.g. Audretsch & Feldman, 1996, 2003; Jaffe et al., 1993). Firms have an incentive to locate near universities, as proximity to academic research centers can reduce the cost of accessing and absorbing knowledge (Audretsch & Lehmann, 2005: 1115). The process by which university knowledge leads to the creation of regional spin-off companies has also been intensively studied, both in terms of the importance of such firms to economic growth (see e.g. Florida & Choen, 1999) but also the creation of regional technology clusters (Audretsch & Lehmann, 2005; Braunerhjelm & Feldman, 2006).

In many research fields, but especially those areas that affect medical research, companies increasingly view academic research findings as directly relevant to corporate R&D (see Lam, 2007). This creates an incentive for companies to develop collaborations with leading university scientists. Research on new technology ventures has also shown that firms founded by prominent university scientists tend to be more successful than firms without such ties. Zucker et al. (1998), for instance, have shown in the case of biotechnology that companies founded by 'star scientists', measured by forward citation counts to their publications, have a higher likelihood of achieving initial public offerings on stock markets, an important milestone in the development of entrepreneurial technology firms. This argument rests partly on the assumption that scientific research linked to prominent scientists has a higher commercial potential compared to the research of lesser-known scientists. However, association with a star-scientist may also help raise the status of a fledgling start-up (Higgins & Gulati, 2003). Doing so might help a company raise finance from venture capitalists and attract talented personnel. For these reasons, entrepreneurs and venture capitalists have a strong motive to cultivate relationships with prominent professors, helping to institutionalize the role of professors within the biotechnology industry.

Recent research on clusters has prioritized university spin-offs as particularly important (Breznitz, 2011; Breznitz et al., 2008). Many prominent university spin-off companies in Silicon Valley, such as Google, Cisco Systems, Sun Microsystems or Genentech, began as tiny firms but have grown into multi-billion-dollar companies employing thousands of individuals and thus strongly impacting local economies. Research on biotechnology clusters has shown that universities within the two large California biotechnology clusters (San Diego and Silicon Valley/San Francisco) have spun off dozens of companies. Stanford, for example, spun off 117 biotechnology firms between 1980 and 2005, while during this time period UC Berkeley and UC San Francisco spun off an additional 87 and 79 firms, respectively (Casper, 2013). About 25% of these firms (68) achieved the significant goal of an initial public offering, again demonstrating significant economic-development impact (Casper, 2009).

Given the demonstration effect provided by Stanford, UC San Francisco and other universities within successful technology clusters, governments have increasingly viewed universities as an important source of regional economic development. The United States was among the first countries to actively encourage the commercialization of federally funded university research through the passage, in 1980, of the Bayh–Dole Act by the United States Congress (for an overview, see Mowery et al., 2004). This legislation established property rights over all federally funded research and, in most cases, transferred ownership to universities. In exchange for receiving ownership of federally funded research, universities are expected to steward this intellectual property and guide its effective commercialization. Most universities responded to the passage of Bayh–Dole by developing technology licensing and transfer offices (TLOs), which assumed responsibility over commercialization processes. Duties of TLOs usually include working with faculty to develop invention disclosures that form the basis for patent applications, filing applications and then licensing the resulting intellectual property to either existing companies or to start-up companies that are spun off from the university.

Most US universities have also created financial incentives for university professors to become active within commercialization processes. While variations exist, many universities have copied Stanford University's system, which divides any profits from licensing into thirds, split between university, department and professors (Colyvas, 2007; Kenney, 1986). Commercialization activities are also encouraged by universities through allowing professors, within employment contracts, to commonly spend up to a day a week on consulting activities. Many universities also encourage professors to become active in the creation of start-up companies. Universities often license the founding technology for a biotechnology start-up to the new company in exchange for equity. Professors active in the founding of the company also receive equity, and typically serve as scientific advisors to the new firm.

Patenting by universities has increased steadily since the passage of the Bayh–Dole Act (Mowery et al., 2004). Academic commercialization practices have been closely studied at a few universities, such as Stanford and MIT, which are widely recognized as successful drivers of local economic growth and cluster development (Etzkowitz, 2002; Shane, 2002). Moreover, a small number of licenses, often surrounding patents for successful drugs or important enabling technologies, can be worth tens and even hundreds of millions of dollars in yearly revenue (see Scherer & Harhoff, 2000). Universities can also profit from equity stakes in start-up companies. The allure of such profits creates an incentive for universities to encourage commercialization (see Thursby & Thursby, 2007, for an overview of university patenting trends). However, research has also consistently found that the ‘payoffs’ from university commercialization vary widely, and that a majority of university technology licenses generate little or no profit (AUTM, 2010).

While universities across the United States have become active in commercialization, most universities have failed to become anchors of regional technology clusters. Within the biotechnology sector, for example, only three regional biotechnology clusters exist in the United States, located in San Francisco, San Diego and Boston. Los Angeles, Chicago, New York City and many other large metropolitan areas have failed to develop meaningful biotechnology clusters despite being home to leading universities and research-oriented medical schools (see Casper, 2009, for a study of Los Angeles). A variety of factors may account for such failures. Los Angeles, for example, has been criticized for having a weak venture-capital community, leading to a lack of finance for local start-ups. On the other hand, New York City is home to a large venture-capital industry, suggesting that other issues must account for its failure to better capitalize on biomedical research emerging from its universities. Overall, however, it is difficult to avoid a conclusion that the existence of strong universities active in commercialization might be a necessary condition to sustain a successful technology cluster, but it surely is not sufficient.

While the discussion so far has centered on the United States, other countries have introduced similar policies toward university commercialization and cluster creation, usually with poor results in terms of cluster creation. A starting-point for many governments has been to introduce equivalents of the Bayh–Dole Act. Germany, the United Kingdom and Japan, for example, all introduced national legislation granting intellectual property ownership of most publicly funded research to universities (see Mowery et al., 2004). Germany has been a country with a particularly active policy of targeting universities as potential anchors of technology clusters. A brief review of German cluster policy in the area of biotechnology helps reaffirm the conclusion that incentivizing universities to commercialize science is not sufficient to create successful clusters.

During most of the post-Second World War period professors in Germany owned intellectual property generated within university-sponsored research. Applied research has been primarily commercialized through relationships with established firms, often underpinned by consulting relationships between individual professors and companies. The system is oriented toward applied-technology fields, such as chemistry and engineering (Abramson et al., 1997). During the late 1990s, however, technology policy within Germany became more oriented toward promoting new-technology industries (see Casper, 2000, 2007a; Lehrer, 2000). Increased support for the commercialization of basic research, particularly within the biomedical sciences, became a core goal of German technology policy. To create stronger incentives for commercialization within universities, the German Parliament passed in 2002 a revised patent law covering university research. Following the US Bayh–Dole framework, the new law transferred ownership of intellectual property surrounding publicly supported research to universities (Kilger & Bartenbach, 2002).

A primary goal of German policies was the creation of spin-off companies from universities. German policy from the mid-1990s onwards has strongly encouraged the creation of university start-up firms, and many of the financial and organizational obstacles to starting companies have been reduced through state programs, especially during the 1995 to 2002 period. To promote the formation of technology clusters, economic development agencies were organized (or in some cases re-purposed) within many German states or *Laender*, often intentionally located in close proximity to major research universities (Lehrer & Asakawa, 2004). Economic development agencies worked closely with university professors to promote the commercialization of research into new ventures, often paying patenting costs, deploying consultants to help develop business development plans, and organizing incubators to help nurture entrepreneurial technology start-ups (Casper, 2000). Federal and local governments have also been active in channeling venture capital to university start-ups, allocating several hundred millions of dollars of funding toward 'public venture capital' to invest in technology start-ups during the 1995 to 2002 period (see Adelberger, 1999: Casper, 2007b, ch. 4). While companies were required to have private investors, state subsidies doubled and sometimes tripled private investments and also provided free or low-cost consultancy services and space within incubators and technology parks.

Hundreds of biotechnology companies were launched in Germany during the 1995–2003 period, most linked to basic science laboratories in German universities. Between 1994 and 2000 the size of the German biotechnology sector grew from fewer than 50 companies to over 350 (see Casper, 2007b). Research on the German biotechnology industry has generally demonstrated that the new sector has performed poorly. While a small number of internationally competitive firms have developed, particularly in the Munich region (see Lange, 2009), German firms have been able to move very few drug candidates through clinical trial pipelines, have not matched the research productivity of the longer-established UK industry, and lag far behind the US industry (see Casper, 2007b). In 2002 a stock market oriented toward new-technology firms, the *Neuer Markt*, crashed and severely depressed the German venture-capital market (see Audretsch & Lehmann, 2005). As a result, very few of the hundreds of small biotechnology firms in the country were able to obtain additional venture-capital financing once the government-subsidized initial funding was gone, leading to a wave of bankruptcies.

A sizable biotechnology cluster has emerged in the Munich area (Jong, 2006), though its origins predate the widespread cluster-creation policies introduced in the mid-1990s, and smaller clusters have survived in Berlin, Heidelberg and Cologne. However, regional clusters failed to develop around the majority of German universities targeted by public policies. As we saw in the discussion of the United States, universities active in commercialization probably are a necessary condition for creating a sustainable technology cluster, but they are not sufficient. Much discussion of the failure in Germany surrounds institutional factors relating to the country's financial system, which could not support high-risk technology start-ups. It is also likely that social networks linking university scientists with experienced entrepreneurs and industry scientists did then not exist in Germany. Both social networks and institutional frameworks relate to variables downstream from university commercialization and, as topics, comprise the other two major perspectives on technology clusters.

Social networks and labor-market mobility

A second approach associates the success of regional technology clusters with the existence of social networks linking entrepreneurs, managers, scientists and engineers. According to this perspective, social networks heighten the performance of clusters through raising the innovative performance of firms while lowering the career risk, from the perspective of individuals, of working within a failure-prone new-technology firm. The social network perspective leads to policy recommendations centered on networking initiatives that have become a common tool within cluster-development initiatives.

The key arguments underlying the social network approach to analyzing regional technology clusters were developed by Saxenian (1994) in her comparison of the Silicon Valley and Route 128/Boston regional semiconductor industries. She argues that Silicon Valley's success is linked to the cultivation of a social structure encouraging the development of numerous informal social networks linking the region's scientists, engineers and managers. Drawing on Granovetter's (1973) research on referral networks within labor markets, Saxenian argues that social networks increased the innovative capacity of area firms through diffusing technological and market intelligence (see also Fleming et al., 2007). The declining fortunes of Route 128's computer and semiconductor industry during the 1980s, on the other hand, are viewed as the outcome of more insular R&D strategies and the predominance of long-term employment within its companies, hindering the creation of information sharing across firms through either social networks or labor-market mobility.

A strength of the social networks and labor-market mobility approach to cluster research is its ability to connect career mobility to the heightened innovative capacity of start-up firms, while also establishing a mechanism through which presumably risk-averse individuals can commit to working within innovative but failure-prone firms. Most start-up companies within new-technology industries such as biotechnology, software or semiconductors begin life as project-based firms organized to recruit and incentivize teams of talented scientists and engineers to work on well-defined technology development goals (Baron & Hannan, 2002; Whitley, 2006). Their success is in part determined by their ability to entice skilled managers and employees to leave lucrative and often 'safe' jobs in established companies or university labs to join a new venture. As discussed in more detail below, common patterns of financing and organizing start-ups enhance the attractiveness of working in these firms. The existence of high-powered performance incentives, usually created through providing equity or stock options to key employees, is an important tool in attracting skilled scientists and managers to a start-up firm. 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. Start-up companies are usually funded by venture capitalists through a series of financing rounds as the firm passes through a series of technical and market milestones developed by its board (Kenney & Florida, 1988). Dismissals of top management are a common response by VC-led boards to firms that have failed to meet development milestones. Managers and employees within start-ups also frequently find themselves at risk of dismissal due to strategic decisions to change the competency structure of the firm.

From the point of view of individuals, there is a strong rationale for choosing to work only within start-up companies embedded within a region in which social ties promoting mobility are strong. Doing so lowers the career risk of working within a start-up by providing numerous alternate employment options should a given venture fail, undergo managerial shake-ups at the behest of investors, or need to change its competency structure due to technological volatility. From this perspective, successful technology clusters develop what Bahrami and Evans (1999) call ‘recycling mechanisms’ to help preserve the value of assets committed to failed enterprises. 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). 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 embeddedness of individuals within social networks makes it safe to do so.

In addition to creating a regional recruiting advantage, social structures facilitating mobility may provide competitive advantage for firms operating in market segments in which technological volatility is high. During the early phase of new industries, technological paradigms are still being established (Utterback, 1996), as firms compete to validate technological approaches and secure property rights or, at times, develop a dominant design (Teece, 1986). To give an example from biotechnology, Penan (1996) used bibliometric data to survey ongoing therapeutics-discovery research in the area of Alzheimer’s disease and found more than 20 distinct technological approaches being pursued by competing teams of biotechnology firms, basic research labs and large pharmaceutical companies. Within such highly uncertain technological environments, companies may need to routinely adjust their portfolio of approaches. The existence of deep, flexible labor markets within a cluster allows firms to more easily use ‘hire-and-fire’ practices to alter research and development strategies. Involvement in social networks 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.

Saxenian’s research on Silicon Valley and Route 128/Boston is part of a long tradition of research suggesting that the competitiveness of local economies is tied to the quality of inter-firm relationships within a region (Herrigel, 1993; Locke, 1999; Piore & Sabel, 1984; Sabel, 1992). Walter Powell and collaborators are particularly important contributors to this research tradition, emphasizing the importance of network forms of organization within science-based industry (Powell, 1996; Powell et al., 1996, 2005) and using network analysis to compare the organization of social ties linking organizations, scientists, entrepreneurs and financiers cross-regionally (Owen-Smith & Powell, 2004). Empirical studies have demonstrated the existence of social networks within several new-technology clusters located in the United States and Europe (see e.g. Almeida & Kogut, 1999; Casper, 2007a, 2013; Fleming et al., 2007; Glimsted & Zander, 2004; Owen-Smith & Powell, 2004).

While helping to explain successful clusters, and especially Silicon Valley, the social network approach also contains an explanation of why many regions fail to create sustainable clusters. 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 informal social networks to employment opportunities at other firms, leaving a safe job to work within a failure-prone start-up becomes a risky proposition. From a career perspective, leaving a safe job in an established company or university to join a start-up truly is a high-risk proposition that most will not choose to accept. It becomes easier to understand why most localities fail to develop successful technology clusters: talented individuals might populate a region, but they face a collective-action problem. They lack the appropriate social ties needed to reduce the risk of working within a high-risk venture.

The social network perspective generates a clear public policy mandate, as governments around the world have embraced networking initiatives as an approach to promote cluster development. The rationale for networking initiatives is straightforward: if successful, they will hasten the process of creating social ties needed to generate the formation and development of firms within a cluster. Networking initiatives are most commonly organized around events designed to attract and intermix members of different communities, such as scientists, entrepreneurs and investors; and take a variety of forms, such as entrepreneurship bootcamps, meetings where scientists can pitch ideas to investors, or panels or speaker events.

More sophisticated policies, found over the last 20 years in both the UK and Germany, involve national governments providing grants of money for regions to organize cluster-development initiatives designed to promote the formation of interdisciplinary teams of scientists and entrepreneurs, who then compete for government resources. Within the biotechnology sector the UK Genetic Knowledge Park Initiative of the mid-2000s (Casper & Murray, 2003) and the German BioRegio program from the mid-1990s (Giesecke, 2000) are good examples of competitive cluster-development programs that emphasized networking. While most government-led networking initiatives are passive, aiming essentially to get the 'right people together in the same room', some governments have introduced more orchestrated approaches. The government of Prince Edward Island, in Canada, as part of an ambitious plan to create a bioscience cluster, actively recruits companies into the cluster through subsidies and tax advantages, and once arrived, commonly offers them R&D grants that explicitly require companies to collaborate with universities and other companies within the cluster. Through doing so, the PEI government hopes to foster inter-organizational R&D networks (see Casper et al., 2010).

A major difficulty facing networking policies, and especially networking initiatives, is that they only lead to the formation of so-called weak ties across individuals within a region. Such acquaintance-oriented ties, while useful in disseminating non-sensitive information or locating referrals, are unlikely to lead individuals to commit to high-risk projects, such as participating in a start-up firm. Recent research on networking has emphasized that networks emphasizing so-called strong ties, often formed on the basis of shared previous experience within high-commitment activities, are more likely to lead individuals to commit to failure-prone activities such as entrepreneurship (see Uzzi & Dunlap, 2005). The 'backbone' of regional social networks consists of strong ties across entrepreneurs and scientists that were shaped by shared experiences, often within one or more key early firms.

The emergence of the San Diego biotechnology cluster is a good example of the importance of strong ties in undergirding high-risk projects. In San Diego a key network emerged linking about two dozen former scientists and senior managers who had worked together at an early regional biotech firm, Hybritech. Launched in 1978, the firm was widely regarded as one of the first successful entrants into the field of molecular diagnostics. It was acquired by the pharmaceutical firm Lilly in 1986 for about US$400 million in cash and company stock, the most expensive biotech acquisition at the time. Difficulties in merging with Lilly led most of Hybritech's senior scientists and managerial staff to leave the company in ensuing years. These individuals shared the experience of building one of the first successful biotechnology firms and had strong working relationships; over a dozen biotech firms were founded by these former managers during the 1986–1990 period. While strong ties helped solidify the founder teams, the high status of these individuals within the San Diego business and science community helped attract talented individuals to the new firms (see Casper, 2007b, Jones, 2003, for more detailed studies of the network formed around Hybritech). To provide another example, Austin, Texas, has emerged as a vibrant cluster of video-game companies. While the existence of the University of Texas in Austin helped fuel the labor market for this cluster, its origins lay in networks of entrepreneurs that emerged from a highly successful early firm, Origin Systems. Richard Garriott, the founder of Origin Systems, was raised in the Silicon Valley area but moved to Texas while in high school as his parents worked in the space program (Donovan, 2005), exemplifying the often idiosyncratic nature of cluster development.

While the San Diego biotechnology example suggests that viable social networks can develop over a few years, the other major theory explaining their existence points to enduring cultural norms within regions. Saxenian's research on Silicon Valley emphasizes culture. Saxenian, as well as other historians of Silicon Valley such as Christoph Lécuyer (2005), stress that the region's culture, emphasizing collaborative R&D and flexible labor markets, emerged over decades as the region's semiconductor industry developed. An interesting facet of Silicon Valley is that norms emphasizing entrepreneurial risk-taking, collaborative R&D and career flexibility, while originating in the electronics industry, have helped spawn a variety of other technology industries that appear to have adopted these practices, such as the biotechnology and Internet software industries. Many other regional technology clusters appear to have succeeded in just one industry, suggesting that social networks form on the basis of local industry norms rather than a broader regional culture. While culture, as a mechanism to diffuse practice, is a powerful instrument, it seems unlikely that public policy, at least within the short to medium term, can have a strong impact on its development (though see research on competition clauses within labor contracts, e.g. Gilson, 1999; Hyde, 1998).

Institutions and competency formation within new-technology firms

The social networks and labor market mobility approaches focus primarily on the analysis of ties linking individuals and organizations; less emphasis is put on the organizational and financial structures used within new technology firms. While a large, diverse institutional literature exists (see e.g. Boyer & Hollingsworth, 1997; Powell & DiMaggio, 1983; Steinmo et al., 1992), research comparing the organization of institutions on a cross-national basis is particularly useful in explaining why some countries have had more success than others in creating clusters focused on new-technology industries. Moreover, recent comparative institutional research has focused directly on the issue of creating competencies within new-technology firms (see Casper, 2007b; Hall & Soskice, 2001; Whitley, 1999). This research suggests that the viability of commonly used organizational and financial strategies within these firms is strongly influenced by the orientation of country-specific institutional frameworks that help structure patterns of finance, corporate governance and labor-market organization. The institutional approach has a straightforward – though difficult to implement – policy recommendation: to emulate regional clusters like Silicon Valley, a country must create the 'right' institutions (this section draws from Casper, 2006; and 2007b, ch. 2).

The analytical strategy employed by recent institutional research is to focus first on typical organizational and financial competencies developed within new-technology firms commonly found in clusters such as Silicon Valley, and then examine how different national institutional frameworks create incentives and constraints that impact the orchestration of the competencies. Research on Silicon Valley (see e.g. Aoki, 2001; Kenney, 2000; Saxenian, 1994) has associated new-technology start-ups with the development of three key competencies: the management of high-risk finance, the development of human resources within a 'competency-destroying' environment and the creation of sufficiently high-powered motivational incentives for personnel. Briefly examining these competencies can help clarify how institutional frameworks impact their governance.

Managing high-risk finance

Successful technology start-ups often generate enormous financial returns. However, as discussed earlier, technological volatility, market uncertainty and competitive rivalry created by frequently low barriers to entry can produce substantial financial risk. Moreover, new-technology firms generally have high 'burn rates' generated by large R&D and marketing costs coupled with low profitability in start-up and expansion phases. This is particularly true in biotechnology, given the high cost and length of clinical trials for new medicines. To obtain financing, most entrepreneurial technology firms use equity-based financing schemes – trading equity within the firm for finance as milestones are achieved in the firm's development. Early equity deals are most commonly made with venture capitalists; then later financing rounds are completed with large firms, institutional investors and, eventually, third-party investors through stock offerings.

Senior managers of entrepreneurial technology firms must manage complex relationships with venture capitalists, investment bankers and other financiers to enable funding of high-risk ventures. This often necessitates the creation of business strategies that can accommodate the creation of milestones negotiated with VCs to justify further funding. However, the viability of equity-leveraged financial plans is also strongly dependent on viable 'exit options' for financiers within financial markets (both to quickly close out unsuccessful investments, but more importantly to exit successful ones through IPOs or, in some cases, mergers or acquisitions). Knowing that the investors can (and will) exit if projects perform poorly puts continual pressure on managers of firms to demonstrate at key milestones that their projects have met growth or earnings targets that justify on-going capital investments.

Developing human resources within a 'competency-destroying' environment

Attracting and retaining staff and managers to work in the risky and dynamic environments of technology start-ups is a second challenge facing most new-technology ventures. As discussed above, hiring and firing is routine at many technology start-ups. When competency destruction is high, managing human resources becomes an important organizational problem (Bahrami & Evans, 1999). To achieve flexibility, managers of technology firms must have the ability to develop new research-and-development competencies while cutting others. To do this, they need access to a pool of scientists, technicians and other specialists with known reputations in particular areas that can quickly be recruited to work on projects. If labor-market flexibility is limited or if there is a cultural stigma attached to failing or changing jobs regularly, then engineers and managers may choose not to commit to firms with high-risk research projects, for fear that, should the project fail, the value of his or her engineering and/or management experiences could significantly decline.

Organizing high-powered motivational incentives for personnel

Managers of technology start-ups must motivate staff to commit to what are often demanding, competitive and time-intensive work environments. Firms often employ performance-based incentive schemes to induce employees to commit to intense work environments. The prospect of large financial rewards helps align the private incentives of engineers and scientists with those of commercial managers (see generally Miller, 1992). In addition to salary increases and performance-related pay, technology companies have primarily used share-options packages, made attractive by the expectation that share value will multiply many times if the company goes public or is sold at a high valuation to another firm. Managers of technology start-ups must be able to credibly maintain high-powered performance incentives.

Institutional arrangements influence the governance of financial and organizational risks within entrepreneurial technology firms. Typologies of national business systems developed by scholars working within the 'varieties of capitalism' field (Hall & Soskice, 2001; Whitley, 1999) are particularly helpful, as these scholars emphasize the role of institutions in structuring patterns of company organization cross-nationally. Based on a relatively simple dichotomy between 'liberal market economies' or LMEs (the US, UK or Canada) and 'coordinated market economies' or CMEs (Germany, Sweden or Japan), these scholars explain how differences in the historical development of key business institutions' governance, industrial relations, finance, labor markets and inter-firm relations influence patterns of industrial organization within an economy. Institutional frameworks influence the activities of firms through providing templates or toolkits that

Table 1. Institutional framework architectures in CMEs and LMEs.

	Coordinated market economies (Germany, Japan, Sweden)	Liberal market economies (United States, United Kingdom, Canada, Australia)
Labor law	Regulative (coordinated system of wage bargaining; high redundancy costs to laying off employees); bias toward long-term employee careers in companies.	Liberal (decentralized wage bargaining; few redundancy costs to laying off employees); few barriers to employee turnover.
Company law	Stakeholder system (two-tier board system plus codetermination rights for employees).	Shareholder system (minimal legal constraints on company organization).
Skill formation	Organized apprenticeship system with substantial involvement from industry. Close links between industry and technical universities in designing curriculum and research.	No systematized apprenticeship system for vocational skills. Links between most universities and firms almost exclusively limited to R&D activities and R&D personnel.
Financial system	Primarily bank based with close links to stakeholder system of corporate governance; no hostile market for corporate control.	Primarily capital-market system, closely linked to market for corporate control and financial ownership and control of firms.

Source: Casper (2007b).

firms may use to structure activity. The orientation of these toolkits advantages the governance of some organizational dilemmas, while impeding others.

While simplifying a great deal the nuance and variety of institutions across countries (see Crouch, 2005), the LME/CME distinction is useful in illustrating the importance of institutional frameworks for supporting or undermining the credibility of broad business models associated with Silicon Valley-type firms. Table 1 highlights some of the primary institutional differences across CMEs and LMEs.

A key argument emerging from the varieties of capitalism perspective is that institutional frameworks within LMEs provide support to firms developing competencies associated with the Silicon Valley model. A brief survey of the US case supports this argument. In the financial area, US-based technology start-ups have been able to organize financial resources through turning to a huge market for high-risk venture capital embedded within supportive, facilitative financial institutions. Most importantly, through the NASDAQ exchange large capital markets exist in which thousands of technology firms have successfully taken listings. A viable exit option allows early-stage investors to adopt a portfolio strategy by diversifying risks across several investments. It also creates a viable refinancing mechanism for venture capitalists (Lerner & Gompers, 2001). Large capital markets and shareholder-dominated corporate governance also create a vibrant market for corporate control. This increases the viability of acquisition as an exit strategy, particularly during periods when market slumps create obstacles to the IPO strategy.

Turning to the issue of achieving internal labor-market flexibility, generally deregulated labor markets in the United States are conducive to the development of extremely deregulated labor markets for engineers and managers within clusters of high-technology firms that have adopted complementary human-resource policies (see Hyde, 1998; Saxenian, 1994). Through lowering the career risk faced by talented personnel who sign on with technologically speculative firms, clusters of technologically intense firms can more easily develop (Almeida & Kogut, 1999; see discussion below). Moreover, the prospect of large financial rewards through realistic IPO scenarios for successful firms coupled with a series of stock-option-friendly finance and industrial relations laws help US technology start-ups easily craft high-powered performance instruments – a prime reason why US high-tech firms have become associated with extremely long work weeks and general dedication to projects.

Until recently, few of these institutional characteristics existed in most Continental European economies. Germany is a useful country for the purposes of comparison, because it provides the clearest contrast to the LME model. Its economy has long been categorized as ‘organized’ or ‘coordinated’. German institutions facilitate the creation of those organizational competencies necessary for firms active in sectors characterized by incremental innovation processes within established industries, such as many segments within the metal-working, engineering and chemicals sectors (Streeck, 1992). Deep patterns of vocational training within firms, consensual decision-making, long-term employment and patient finance are all linked to the systematic exploitation of established technologies via a wide variety of niche markets, a strategy Streeck (1992) labels ‘diversified quality production’. On the other hand, the regulative nature of German economic institutions combined with pervasive non-market patterns of coordination within the economy create constraints on the organization of industries that perform best within shorter-term, market-based patterns of coordination (Casper et al., 1999).

A brief survey demonstrates the weak institutional support for internal labor-market flexibility within German entrepreneurial technology firms. Germany’s customary credit-based financial system excels at providing ‘patient finance’ to firms in traditional sectors with relatively low long-term risk, but sets up obstacles to the financing of more risky entrepreneurial projects (Edwards & Fischer, 1994). Venture capital is hard to sustain in countries without large capital markets willing to support high-risk initial public offerings. In addition to often-discussed financing ‘gaps’ in high-risk capital within bank-centered financial systems, the lack of experienced venture capitalists with in-depth industry knowledge and contacts creates additional difficulties (see Tylecote & Conesa, 1999). Germany’s bank-centered financial system also tends to dampen ownership-related incentives through muting the effectiveness of share dispersal schemes. Without a realistic possibility of taking an initial public offering, the performance incentive provided by stock options or outright share dispersals is weakened (though merger activity or management buy-outs provide weaker exit options).

In Germany, stakeholder-based company laws combine with high financial burdens on employee dismissals to promote long-term employment within firms. Labor law cedes a formal right for staff at all firms with more than five employees to form a works council, which holds important bargaining rights over personnel policy, training and overtime. Within German manufacturing firms, works councils usually demand long-term employment guarantees in return for flexibility in work organization and overtime negotiations (see Streeck, 1992). This helps the management of German firms to convince their workers to invest in skills or knowledge that are often tacit or firm-specific and thus difficult to sell on the open labor market. While 'competency enhancement' within organizations is strong within Germany, it systematically inhibits the creation of the active labor markets needed to create incentives for firms and their employees to embark on high-risk projects with a strong possibility of failure. Similarly, limits on hiring and firing make it difficult for firms to compete in rapidly developing fields where the required research competencies change quickly.

In sum, core German market institutions are primarily geared toward the creation of firm-level competencies needed to create sustained, incremental innovation patterns in industries with lower scientific intensity. The result during the 1980s and early 1990s was poor performance in most sectors with technological profiles that are best advantaged through the creation of entrepreneurial business models (see Casper et al., 1999). Germany lacks institutions to systematically nurture the development of entrepreneurial competencies. While the German institutional system may be the one with an orientation most clearly hostile to promoting new-technology firms, similar institutional arrangements exist in many other European economies (see e.g. Gittelman, 2006; Kogut, 2004).

The institutional approach has a straightforward, but difficult to implement, public policy implication: countries should reform institutional frameworks to introduce the 'correct' institutions in support of new technologies. Doing so will create institutions supportive of technology-cluster development. Broadly speaking, policies should aim to create institutional frameworks similar to those within LMEs: labor-market laws supportive of flexible labor markets, shareholder-dominated corporate governance systems and capital-market-based financial systems supportive of venture capital. Recent research in the field of entrepreneurship has adopted this approach, emphasizing that new firms are in need of an institutional infrastructure that generates an abundance of resources for entrepreneurial firms and thus lowers entrance barriers. Creating institutions supportive of venture capital, market-based industrial organization and open labor markets are key recommendations (see Audretsch & Thurik, 2000). The creation of market-oriented laws governing intellectual property developed at universities, as discussed above, is also consistent with the institutional perspective. Recent recommendations from the Organization for Economic Co-operation and Development (OECD), the European Commission and the Global Entrepreneurship Monitor also recommend that institutions be redesigned to better support entrepreneurship (see Kelley et al., 2011; OECD, 2010).

One of the clearest examples of governments embracing policies aligned with the institutional approach is German attitudes toward public policy during the 1993–2003 period, as discussed earlier in connection with policy toward universities. German policy in this period systematically attempted to create institutional frameworks supportive of high-technology entrepreneurship (see Casper, 2007b; Lehrer, 2000). In addition to the creation of 'public venture capital', mentioned earlier, the German government worked with the owners of the Frankfurt stock market to create a new exchange model inspired by the US Nasdaq market and focused on new-technology stocks: this was known as the *Neuer Markt*. In 1998 the German government also introduced new financial regulations allowing firms to buy and sell their own shares, legislation needed to allow German firms to introduce stock options for employees. While no changes were made to labor-market laws, the provision of widespread 'public' venture capital to start-ups enticed thousands of individuals with life-science training to work in entrepreneurial biotechnology ventures, as several hundred biotechnology firms were founded during this period.

As mentioned earlier, the German biotechnology firms faced difficulties in translating scientific discoveries into drugs that could move into clinical trials. The collapse of venture capital markets in the United States and Europe during the 2002–2004 period, caused by the bursting of the 'dot-com' bubble, hastened the downfall of dozens of German biotechnology firms, which could no longer raise additional finance. The failure of German policy to create institutions capable of generating viable markets in two areas, finance and highly skilled labor, provide a primary explanation for the failure of German policy to create new-technology clusters in biotechnology and other fields (see Casper & Whitley, 2004). In the area of labor markets, research has shown that German biotechnology firms were unable to attract experienced managers working within the large domestic pharmaceutical industry to take jobs in risky start-up firms (see Casper, 2007b, ch. 4). One explanation for this is the predominance of long-term employment within large German firms, which limits the labor market for mid-career professionals. An important cause of the failure of many German biotechnology firms is their inability to hire professionals with experience in pharmaceutical development, the process of taking candidate drugs through the pre-clinical and clinical trials processes.

The failure of the German government to revamp institutional frameworks to better support new-technology clusters helps bring forward two more general points. First, as argued by theorists within the comparative capitalism field, complementarities exist across institutions (see Hall & Soskice, 2001). In other words, piecemeal institutional reforms are unlikely to succeed. German policy helped create corporate governance rules allowing small firms to adopt corporate governance and employee incentive structures commonly found within small US technology companies, and for a time generated a vibrant venture-capital market. However, policies could not create labor-market institutions capable of generating large, flexible labor markets, particularly for mid-career professionals. Lacking access to key human-resource competencies, German technology firms could not successfully innovate in drug development. This leads to the second point. From a policy perspective it is difficult to change institutional frameworks that work across multiple sectors within an economy, such as labor-market regulations. While restrictive German labor-market practices appear dysfunctional from the perspective of high-technology start-ups, there is a large literature demonstrating how 'beneficial constraints' on employers, for example in hiring and firing, create incentives for German firms to invest in areas such as the intensive training of employees (Streeck, 1992). As a result, the German government, despite a conservative orientation during the 1993–2003 period, did not attempt to introduce reforms to either its labor-market or industrial-relations systems (see Wood, 2001). Overall, while the recipe for promoting high-technology firms and clusters through introducing institutions modeled on the liberal market model is straightforward, implementing it can be extremely difficult politically.

Coordinated market economies, such as those of Japan, Germany or other Northern European countries, appear much less likely to develop large clusters of new-technology firms. One option for coordinated market economies is to focus on creating clusters within more 'incrementally innovative' segments of new-technology industries. Germany's successful machine-tool cluster in Baden-Wurttemberg focuses on incrementally innovative technologies (Herrigel, 1993). Many new-technology industries include segments within which innovation is more incremental. Examples include enterprise software and the large 'toolkit' segment within the biotechnology industry. Two of Germany's most successful large technology-oriented firms, SAP in software and Qiagen in biotechnology, have adopted this strategy. Success in enterprise software and biotechnology toolkits depends on the creation of strong, long-term relationships with customers and the creation of interdisciplinary R&D teams, often linking marketing and research personnel (see Casper & Whitley, 2004), strategies that resonate well with institutional incentives created for coordinated market economies. Although recognized as important, neither a strong external R&D orientation nor access to flexible labor markets appears central to this strategy, with the implication that the existence of clusters is not a strong driver of performance. Neither the Heidelberg nor Düsseldorf regions, the locations of Qiagen and SAP respectively, is home to a substantial cluster in software or biotechnology.

A second strategy for developing clusters within coordinated clusters is to create institutional environments on a regional basis that, in effect, circumvent broader national institutional frameworks. A key problem here is developing social norms and networks within a region needed to sustain highly flexible labor markets. We have seen the difficulty of creating such networks in countries, like the United States, with broadly deregulated labor markets at the national level. In countries where long-term employment is the norm, moving to a flexible labor-market equilibrium at a local level would seem difficult. However, the success over the last 15 years of Sweden's Stockholm region in wireless communication policies provides one example. Glimsted and Zander (2004) have documented the existence of a strong new-technology cluster in Stockholm, supporting dozens of wireless software start-ups. Their research shows that the large telecommunications provider, Ericsson, has played a major role in the development of the sector. Ericsson has sponsored important open-wireless communication standards, such as Bluetooth, while at the same time creating an internal corporate-venture program that has encouraged its own employees to form local start-ups. According to Glimsted and Zander, Ericsson made an implicit commitment that engineers leaving the firm to work in a high-risk start-up could return to Ericsson should the firm fail. In effect, Ericsson created a technology environment where local start-ups likely had a first-mover advantage in creating technologies around new communication standards, while also lessening the career risk of leaving a safe job, particularly within a low-mobility labor market, to become an entrepreneur. This example shows that regional institutions can emerge in support of new-technology clusters within coordinated market economies, though the key driver of cluster creation was again a firm rather than the government.

Concluding analysis

How do high-technology clusters emerge, and what makes them sustainable? The three perspectives surveyed here offer different, but complementary explanations of why clusters exist, along with corresponding policy recommendations. Table 2 summarizes the three perspectives.

Several conclusions can be drawn from this analysis. The first is that regional technology clusters are more sustainable within liberal market economies, as these countries have the 'right' institutions to support industries in which non-cumulative or radical innovation exists. However, as discussed earlier, the existence of a strong research university, while perhaps a necessary condition in fields such as biotechnology, is clearly not sufficient, as shown by the failure of many regions with strong universities in the United States to generate meaningful biotechnology clusters. It is likely that the missing variable within many regions in liberal market economies are the social networks conducive to both information sharing and strong regional labor-market mobility – both key drivers of cluster success in Silicon Valley.

Countries with institutions conducive toward non-market or 'coordinated' patterns of economic organization face a difficult challenge in creating technology clusters focused on the Silicon Valley model of financing, staffing and organizing companies. Aside from the idea of creating countervailing institutions on a regional level – as possibly seen with Stockholm's wireless technology cluster – the public policy challenge of rewiring a country's institutional set-up to support new-technology entrepreneurship appears daunting, as the failure of German policy toward biotechnology shows. A more realistic

Table 2. Summary of the three perspectives on cluster performance.

Approach	Key driver of cluster success	Key concern	Policy recommendation
Universities and spillovers	Generating spillovers from universities into regional economies.	University policies and/or national regulation dampen the commercialization of university discoveries.	Policies aimed to enhance university commercialization.
Social networks	Promoting heightened innovation and lowering the career risk of working within a start-up.	Inadequate social-network formation.	Networking policy; prospecting.
Institutions	Creating viable organizational structures and financing for new-technology start-ups.	National institutional frameworks in the areas of finance, corporate governance and labor-market regulation not aligned with the needs of new-technology firms.	Introduce the 'correct' institutions to support new-technology start-ups.

alternative for countries with organized or coordinated institutional set-ups is to focus policy initiatives on industries, or sub-sectors of industries, in which innovation is more cumulative. The success of German firms in enterprise software and the toolkit segment of biotechnology is indicative. While this review focused on governments as agents of cluster creation, empirical evidence suggests that large firms can have a major role. Examples discussed in our review include Hybritech's impact on social-network formation, in the San Diego biotechnology cluster, and Ericsson's policies, which helped reduce the career risk of becoming an entrepreneur in the Stockholm wireless cluster. Both indirectly and directly, large companies can have a major impact on cluster development in ways that governments may not. Managers of Hybritech, for example, in no way planned to help construct the San Diego biotechnology cluster. However, the shared experience between dozens of managers and scientists of creating a successful company became the basis of the region's entrepreneurial social networks (see generally Uzzi & Dunlap, 2005). It is hard to imagine governments achieving a similar outcome with regional cluster policies, as similar shared entrepreneurial experiences are difficult to forge within a non-market context. Building a larger repertoire of empirical studies demonstrating how companies impact cluster formation, both positively and negatively, is an important task for future research on technology clusters.

The analysis here has emphasized the nesting of key elements for strong cluster performance: universities, social networks and companies organized within an appropriate institutional environment. Successful clusters have large, active markets for technology, finance and human capital, as well as a community of individuals willing to start new firms, share information or help mentor scientists, engineers and entrepreneurs looking to work within the local technology sector. This sense of practice is more difficult to capture within academic overviews and, once again, seems difficult to shape through public policy. Yet it forms the key ingredient of all successful clusters. Table 3 illustrates common enabling practices within clusters, situated between common company strategies in new-technology strategies and supportive national institutional environments.

To conclude, is there a role for governments in creating successful new-technology clusters? While there is, it must be aligned with broader institutional frameworks within a particular country, and is not likely to be the primary catalyst in creating a successful cluster. Governments everywhere should support the creation of basic university research and encourage its translation and commercialization. Clusters can exist in all countries, though the more 'radically innovative' ones are likely to emerge in countries with a liberal market rather than organized or industry-coordinated institutional set-ups. But even within liberal market economies, the key networks that seem to support all successful new-technology clusters frequently have their origins in early firms, which go on to spawn additional firms within a region and, through doing so, develop the key early networks that drive the creation of a credible labor market. Given the importance of meaningful shared experience across networks of entrepreneurs, it seems difficult for governments to seed similar networks through policy. A more promising approach among coordinated economies is for governments to support company creation in more incrementally innovative areas of high technology – areas where firms in such countries are likely to have a competitive advantage.

Table 3. Company strategies, regional practices and national institutional frameworks in support of new-technology clusters.

Company strategy	Enabling practices within clusters	Supportive national institutional frameworks
Ability to quickly assemble and if necessary shed talented mid-career managers, scientists and engineers.	Large labor market for mid-career professionals exists within the cluster, supported through cohesive social networks linking professionals within a cluster. This market is created by practices of frequent job-hopping, entry/exit of companies, and hire/fire strategies.	Deregulated labor markets, weak rules protecting skilled labor within industrial relations system.
Ability to create 'high-powered' incentives by using equity grants and stock options to reward individual performance.	A strong history of IPOs and company acquisitions exists within the cluster, such that skilled employees are confident that equity stakes/stock options can be monetized if the firm is successful.	Capital-market-based financial system with corporate governance rules favoring shareholders over other stakeholders.
Ability to raise financing for high-risk projects.	A sizeable agglomeration of companies exists within a given technology segment within the cluster, allowing VCs focused on early-stage investments to credibly diversify risks through developing portfolio investment strategies. Use of milestone-based investment strategies and syndicate patterns to diversify risks.	Capital-market-based financial system with corporate governance rules favoring shareholders over other stakeholders.
Ability to in-license technology from universities and develop tacit-knowledge links with local university laboratories.	Local universities anchor a market for technologies within a cluster, creating local inventor networks and collaborations linking university labs and firms.	Laws exist creating intellectual property rights for technology granted to universities through government funding (contested: rules granting ownership of government funded IP to universities).

References

Abramson N, Encarnacao J, Reid P, Schmoch U (eds) (1997) *Technology Transfer Systems in the United States and Germany*. Washington, DC: National Academy Press.

Adelberger KE (1999) A developmental German state? Explaining growth in German biotechnology and venture capital. *Berkeley Roundtable on the International Economy (*Working Paper 134). Available at: http://brie.berkeley.edu/publications/WP134.pdf

Almeida P, Kogut B (1999) Localization of knowledge and the mobility of engineers in regional networks. *Management Science* 45: 905–917.
Aoki M (2001) *Toward a Comparative Institutional Analysis*. Cambridge, MA: MIT Press.
Arrow K (1962) Economic welfare and the allocation of resources for invention. In: Nelson R (ed.) *The Rate and Direction of Inventive Activity: Economic and social factors*. Princeton, NJ: Princeton University Press, 609–625.
Audretsch DB, Feldman MP (1996) R&D spillovers and the geography of innovation and production. *American Economic Review* 86: 630–640.
Audretsch DB, Feldman MP (2003) Knowledge spillovers and the geography of innovation. In: Henderson VJ, Thisse J (eds) *Handbook of Urban and Regional Economics*, Volume 4. Amsterdam: North Holland Publishing.
Audretsch DB, Lehmann E (2005) Does the knowledge spillover theory of entrepreneurship hold for regions? *Research Policy* 34: 1191–1202.
Audretsch DB, Thurik AR (2000) Capitalism and democracy in the 21st Century: From the managed to the entrepreneurial economy. *Journal of Evolutionary Economics* 10: 17–34.
AUTM (2010) *The AUTM Licensing Survey, FY 2010*. Norwalk, CT: Association of University Technology Managers.
Bahrami H, Evans S (1999) Flexible re-cycling and high-technology entrepreneurship. *California Management Review* 37: 62–88.
Baron J, Hannan T (2002) Organizational blueprints for success in high-tech start-ups: Lessons from the Stanford Project on Emerging Companies. *California Management Review* 44: 8–36.
Boyer R, Hollingsworth JR (1997) *Contemporary Capitalism: The embeddedness of institutions*. Cambridge: Cambridge University Press.
Braunerhjelm P, Feldman M (eds) (2006) *Cluster Genesis: Technology-based industrial development*. Oxford: Oxford University Press.
Breschi S, Malerba F (eds) (2007) *Clusters, Networks, and Innovation*. Oxford: Oxford University Press.
Breznitz S (2011) Improving or impairing? Following technology transfer changes at the University of Cambridge. *Regional Studies* 45: 463–478.
Breznitz S, O'Shea R, Allen T (2008) The role of research universities in the development of regional bioclusters: A study of MIT and Yale commercialization strategies. *The Journal of Product Innovation Management* 25: 129–142.
Casper S (2000) Institutional adaptiveness, technology policy, and the diffusion of new business models: The case of German biotechnology. *Organization Studies* 21: 887–914.
Casper S (2006) 'Exporting Silicon Valley to Europe: How useful is comparative institutional theory?' In: Hage J, Meeus M (eds) *Handbook on Institutions and Institutional Change*. 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 toward new technology industries*. Oxford: Oxford University Press.
Casper S (2009) *The marketplace for ideas: Can Los Angeles build a successful biotechnology cluster?* Report to the John Randolph Haynes Foundation. Available at: http://www.kgi.edu/Documents/In_the_news/Casper%20Biotech%20Report%20Final.pdf
Casper S (2013) The spill-over theory reversed: The impact of regional economies on the commercialization of university science. *Research Policy* (in press).
Casper S, Murray F (2003) Examining the marketplace for ideas: How local are European biotechnology clusters. In: McKelvey M, Hageman J (eds) *Industrial Dynamics in European Biotechnology*. London: Edward Elgar.

Casper S, Murray F (2004) Careers and clusters: Analyzing career network dynamics of biotechnology clusters. *Journal of Engineering and Technology Management* 22: 51–74.
Casper S, Whitley F (2004) Managing competences in entrepreneurial technology firms: A comparative institutional analysis of Germany, Sweden and the UK. *Research Policy* 33: 89–106.
Casper S, Lehrer M, Soskice D (1999) Can high-technology industries prosper in Germany? Institutional frameworks and the evolution of the German software and biotechnology industries. *Industry and Innovation* 6: 5–24.
Casper S, McNevin A, Krausse J (2010) The Prince Edward Island biotechnology cluster: Creating a knowledge-based economy. In: Ahn M, Alvarez M, Meyers A, York A (eds) *Building the Case for Biotechnology*. New York, NY: Ingram, Baker & Taylor, 167–188.
Colyvas JA (2007) From divergent meanings to common practices: The early institutionalization of technology transfer in the life sciences at Stanford University. *Research Policy* 36: 456–476.
Crouch C (2005) *Capitalist Diversity and Change: Recombinant governance and institutional entrepreneurs*. Oxford: Oxford University Press.
DeVol P, Ki J, Bedroussian A, Koepp R (2005) *America's Biotech and Life Science Clusters: San Diego's position and economic contributions*. Los Angeles, CA: Milken Institute.
Donovan T (2005) *Replay: The history of video games*. Lewes: Yellow Ant.
Edwards J, Fischer K (1994) *Banks, Finance and Investment in Germany*. Cambridge: Cambridge University Press.
Etzkowitz H (2002) *MIT and the Rise of Entrepreneurial Science*. London: Routledge.
Fleming L, King C, Juda A (2007) Small worlds and innovation. *Organization Science* 18: 938–954.
Florax R (1992) *The University – a Regional Booster? Economic impacts of academic knowledge infrastructure*. Aldershot: Avebury.
Florida R, Choen WM (1999) Engine or infrastructure? The university role in economic development. In: Brandscome LM, Kodama F, Florida R (eds) *Industrializing Knowledge: University–industry linkages in Japan and the US*. Cambridge: MIT Press.
Giesecke S (2000) The contrasting roles of government in the development of biotechnology industry in the US and Germany. *Research Policy* 29: 205–223.
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: 575–629.
Gittelman M (2006) National institutions, public–private knowledge flows, and innovation performance: A comparative study of the biotechnology industry in the United States and France. *Research Policy* 35(7): 1052–1068.
Glimstedt H, Zander U (2004) Sweden's wireless wonders: Defining the Swedish internet economy. In: Kogut B (ed.) *The Global Internet Economy*. Cambridge, MA: MIT Press.
Granovetter M (1973) The strength of weak ties. *American Journal of Sociology* 78: 1360–1380.
Hage G (2011) *Restoring the Innovative Edge*. Stanford, CA: Stanford University Press.
Hall PA, Soskice D (eds) (2001) *Varieties of Capitalism: The institutional foundations of comparative advantage*. Oxford: Oxford University 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, Gulati R (2003) Getting off to a good start: The effects of upper echelon affiliations on interorganizational endorsements. *Organization Science* 14: 244–263.
Hyde A (1998) Employment law after the death of employment. *University of Pennsylvania Journal of Labor Law* 1: 105–120.
Jaffe A, Trajtenberg M, Henderson R (1993) Geographic localization of knowledge spillovers, as evidenced by patent citations. *Quarterly Journal of Economics* 108: 863–911.
Jones M (2003) *Biotech's perfect climate: The hybritech story*. Doctoral dissertation, University of California at San Diego.

Jong S (2006) The development of Munich and Cambridge therapeutic biotech firms: A case study of institutional adaptation. *European University Institute* Working Paper. Available at: http://cadmus.eui.eu/handle/1814/6433.

Kelley JD, Bosma N, Amorós JE (2011) *GEM (Global Entrepreneurship Monitor)*. Global Entrepreneurship Research Association (GERA). Available at: http://www.gemconsortium.org/docs/2409/gem-2011-global-report

Kenney M (1986) *Biotechnology: The university–industrial complex*. New Haven, CT: Yale University Press.

Kenney M (ed.) (2000) *Understanding Silicon Valley: The anatomy of an entrepreneurial region*. Palo Alto, CA: Stanford University Press.

Kenney M, Florida R (1988) Venture-capital financed innovation and technological change in the USA. *Research Policy* 17: 119–139.

Kilger C, Bartenbach K (2002) New rules for German professors. *Science* 298: 1173–1175.

Kogut B. (2004) *The Global Internet Economy*. Cambridge, MA: MIT Press.

Lam A (2007) Knowledge networks and careers: Academic scientists in industry–university links. *Journal of Management Studies* 44: 993–1016.

Lange K. (2009) Institutional embeddedness and the strategic leeway of actors: The case of the German therapeutic biotech industry. *Socio-Economic Review* 7: 181–207.

Lécuyer C (2005) *Making Silicon Valley: Innovation and the growth of high tech, 1930–1970*. Cambridge, MA: MIT Press.

Lehrer M (2000) Has Germany finally fixed its high-tech problem? The recent boom in German technology-based entrepreneurship. *California Management Review* 42(4): 89–107.

Lehrer M, Asakawa K (2004) Pushing scientists into the marketplace: Promoting science entrepreneurship. *California Management Review* 46(3): 55–76.

Lerner J, Gompers P (2001) *The Money of Invention: How venture capital creates new wealth*. Cambridge, MA: Harvard Business School Press.

Locke R (1999) *Remaking the Italian Economy*. Ithaca, NY: Cornell University Press.

Miller G (1992) *Managerial Dilemmas*. Cambridge: Cambridge University Press.

Mowery D, Nelson R (eds) (1999) *Sources of Industrial Leadership: Studies of seven industries*. Cambridge: Cambridge University Press.

Mowery D, Nelson R, Sampat B, Ziedonis A (2004), *Ivory Tower and Industrial Innovation: University–industry technology transfer before and after the Bayh–Dole Act in the United States*. Palo Alto, CA: Stanford University Press.

National Academies (2007) *Rising above the Gathering Storm: Energizing and employing America for a brighter economic future*. Washington, DC: The National Academies Press.

OECD (2010) *Ministerial Report on the OECD Innovation Strategy, Innovation to Strengthen Growth and Address Global and Social Challenges – Key Findings*. Paris: OECD.

Owen-Smith J, Powell W (2004) Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science* 51: 5–21.

Penan H (1996) R&D strategy in a techno-economic network: Alzheimer's disease therapeutic strategies. *Research Policy* 25: 337–358.

Porter M (1998) Clusters and the new economics of competition. *Harvard Business Review* 76: 77–90.

Piore M, Sabel C (1984) *The Second Industrial Divide*. New York, NY: Basic Books.

Powell W (1996) Inter-Organizational Collaboration in the Biotechnology Industry. *Journal of Institutional and Theoretical Economics* 120: 97–215.

Powell W (1998) Learning from collaboration: Knowledge and networks in the biotechnology and pharmaceutical industries. *California Management Review* 40: 228–240.

Powell W, DiMaggio PJ (1983) The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields, *American Sociological Review* 48: 147–160.

Powell W, Loput K, Smith-Doerr L (1996) Inter-organizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly* 41: 116–145.

Powell W, White D, Loput K, Owen-Smith J (2005) Network dynamics and field evolution: The growth of inter-organizational collaboration in the life sciences. *American Journal of Sociology* 110(4): 1132–1205.

Rosenberg N, Nelson R (1994) American universities and technical advance in industry. *Research Policy* 23: 323–348.

Rosenberg N, Nelson R (1996) The roles of universities in the advance of industrial technology. In: Rosenbloom RS, Spencer WJ (eds) *Engines of Innovation: US industrial research and the end of an era*. Cambridge, MA: Harvard Business School Press, 87–109.

Sabel C (1992) Studied trust: Building new forms of cooperation in a volatile economy. In: Swedberg R (ed.) *Explorations in Economic Sociology*. New York, NY: Russell Sage Foundation, 104–144.

Saxenian A (1994) *Regional Advantage: Culture and competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.

Scherer FM, Harhoff D (2000) Technology policy for a world of skew-distributed outcomes. *Research Policy* 29: 559–566.

Shane S (2002) Selling university technology: Patterns from MIT. *Management Science* 48: 122–137.

Steinmo S, Thelen K, Longstreth F (eds) (1992) *Structuring Politics: Historical institutionalism in comparative analysis*. New York: Cambridge University Press.

Streeck W (1992), *Social Institutions and Economic Performance: Studies of industrial relations in advanced capitalist economies*. London/Beverly Hills, CA: SAGE Publications.

Teece D (1986) Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy. *Research Policy* 15: 285–305.

Thursby J, Thursby M (2007) University licensing. *Oxford Review of Economic Policy* 23: 620–639.

Tylecote A, Conesa E (1999) Corporate governance, innovation systems and industrial performance. *Industry and Innovation* 6: 25–50.

Utterback J (1996) *Mastering the Dynamics of Innovation*. Cambridge, MA: *Harvard University Press*.

Uzzi B, Dunlap S (2005) How to build your network. *Harvard Business Review* 83: 53–60.

Von Hippel E (1994) 'Sticky information' and the locus of problem solving: Implications for innovation. *Management Science* 40(4): 429–439.

Whitley R (1999) *Divergent Capitalisms: The social structuring and change of business systems*. Oxford: Oxford University Press.

Whitley R (2006) Project-based firms: New organizational form or variations on a theme? *Industrial and Corporate Change* 15: 77–99.

Wood S (2001) Business, government and patterns of labor market policy in Britain and the Federal Republic of Germany, in Hall P, Soskice D (eds) *Varieties of Capitalism: The institutional foundations of comparative advantage*. Oxford: Oxford University Press, 247–274.

Zucker L, Darby M, Brewer M (1998) Intellectual human capital and the birth of US biotechnology enterprises. *American Economic Review* 88: 290–306.

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