Making Science Cities:

The "Triple Helix" of Regional Growth and Renewal[1]

Henry Etzkowitz[2]

Abstract

The two leading U.S. high-tech regions, Route 128 and Silicon Valley, were built on "Brownfield" and "Greenfield" sites. Drawing upon academic, business and government resources, a coalition of New England academic institutions and financial interests created a new model of regional economic development in the early post-war. Follow-on regions typically identify successful models and adapt them to meet their needs (Rosenberg, 2001). Thus, the venture capital model was transferred from Boston to northern California to expand firm formation activity in the emerging semi-conductor industry. Silicon Valley, based on a flat network structure, is currently being transformed into a planetary system of strong entities with satellites. A triple helix model of university-industry-government relations and science-based economic growth is derived from the experience of these prototypical Science Cities.

Introduction

Science cities are regional development projects, based upon university-industry-government collaborations, that creatively synthesize local and national resources to achieve science-based economic growth. They typically have an entrepreneurial university as their cornerstone. The two leading "Science Cities" in the United States, Route 128 and Silicon Valley, originated from seemingly improbable circumstances. Boston in the 1930's was a declining industrial region that had lost most of its traditional industry to the South. Santa Clara County in northern California, in the 1950's, was an agricultural region known as the "Valley of Hearts Delight" for its abundant production of fruits and nuts. How did these two strongly contrasting regions develop as the leading centres of science-based industry in the U.S. in subsequent decades? [3]

---

[1] An earlier version was presented as the keynote Address to the Science Cities National Workshop, York, England, 23 September 2005. I wish to thank various participants for their perceptive comments, most helpful in revising.

[2] Chair in Management of Innovation, Business School, University of Newcastle Upon Tyne and Visiting Professor, Department of Technology and Society, School of Engineering and Applied Sciences, Stony Brook University Email: henry.etzkowitz@ncl.ac.uk

[3] Method: This paper is based on archival research and dialogic interviews with key informants. Archival research was conducted at MIT Archives, Leahy Business Archives, Stanford University Archives and the California Historical Society. Interviews were conducted in 1986-87 with

A simple answer is the presence of MIT and Stanford. While these two universities played an important role in transforming their regions it was not the university by itself that made the difference. Indeed, other regions had greater universities than Stanford in the 1950's, which was only just becoming a leading research university. What these two regions had in common were (1) universities with research capacity in fields with conjoint practical and theoretical relevance; (2) faculty and administrators interested in using these scientific and technological resources to develop the local region, and (3) collaborative efforts among university, industry and government to implement this strategy.

The emergence of polyvalent research fields with simultaneous theoretical, technological and commercial potential provides a substrate for the growth of science based clusters.[4] The recognition that knowledge is imbued with multiple attributes encouraged the multiple roles of academics and their involvement in bio-technology firms and of industrial researchers in academic pursuits. Univalent knowledge follows a sequence from basic to applied research typically carried out in different time periods, at different sites, and by different persons. The emergence of polyvalent knowledge called forth the concept of translational research (a fuzzier notion than applied research) and an activity that is closely associated with fundamental investigation and likely to be conducted in tandem.

---

members of American Research and Development, faculty and administrators at MIT and Harvard and in 2005 with organizers of Angel Networks, Venture Capitalists, faculty and administrators at Stanford. Appreciation is expressed to Harvard's History of Science Department and Stanford's Office of Technology Licensing for providing a base as a Visiting Scholar.

[4] In contrast to the division of knowledge into divergent epistemological spheres e.g. Pasteur, Edison and Bohr's Quadrants (Stokes, 1997); the polyvalency thesis holds for the unity of knowledge, with complementary aspects. Indeed, even the namesakes of these Quadrants spill over into others. For example, the "Edison effect" might well fit into Bohr's space. See also Viale and Etzkowitz theme paper for the 5th Triple Helix conference. www.triple.helix5.com

In recent decades, academic and government research entrepreneurs have promoted the development of fields, like nanotechnology, that are expected to be the source of future economic activity (Rocco, 2001).[5] In Boston during the 1960's, with the rise of the mini-computer industry, and in Silicon Valley during the 1970's and 80's, with the growth of the semiconductor and personal computer industries, a myth arose of spontaneous generation of high-tech economic growth. These regions appeared to be successful purely on the basis of business activity, through spin-offs that created clusters where there had been single companies. The role of university and government only became apparent in crises. This paper analyzes two prototypical science cities to derive a triple helix model of regional growth and renewal.

Renewing an Old Industrial Region

It was apparent in Boston, early in the 20th century, that it was necessary to replace firms, whose technologies and products were outmoded, or that had moved elsewhere. The Boston area, had begun the industrialization of the United States with textiles, shoe and then machine tool production but these industries gradually moved elsewhere to be closer to sources of raw materials and customers. In response to long term economic decline from the turn of the century, the region's business and political leadership, including the governors of the six New England states and industry representatives organized the New England Council, in 1925, to renew the region. The Council soon drew University presidents, like MIT's Karl Compton, into its membership.

MIT was a special feature of the region, having been founded in 1862, as a unique industrial variant of the Land grant universities, established in each state to support the development of agriculture, the nation's major industry at the time (Rossiter, 1973). The land grant schools focused on practical subjects rather than the classic liberal arts, although the latter were also included in the curriculum. MIT was designed as a

[5] In the inter-war period, the entrepreneurial role in synthesizing new fields was often played by Foundation executives like Warren Weaver of the Rockefeller Foundation, who contributed in various ways to the development of molecular biology, not the least by making a strategic series of grants (Abir-am, 1985). For another case study of Polyvalency see Steve Heims John von Neumann and Norbert Weiner: From Mathematics to the Technologies of Life and Death (Cambridge: MIT Press, 1982), on cybernetics in the early post-war.

technological university, to train students and infuse new ideas into the region's industrial economy but also to conduct basic research and pursue those liberal arts with technological relevance like the history of science and technology.

MIT's academic model was broader than specialized engineering schools of the era such as West Point, with its military focus, or Rensselaer Polytechnic Institute, oriented to civil engineering in support of infrastructure projects like the Erie Canal. Drawing upon the European polytechnic tradition, William Barton Rogers, MIT's founder, envisioned the Institute as a source of new industrial technology from fundamental research. His vision was realized gradually since lack of resources forced MIT to function as an engineering teaching college until the end of the 19^{th} century when it began to develop research and an entrepreneurial culture (Etzkowitz, 2002).

Founded to support existing industry, MIT eventually found its true regional role as a source of new industry through the New England Council a regional development effort. The Council's committees explored strategies, commissioned studies and reported back results to the larger body for discussion and action. Beginning its efforts based on conventional regional economic development strategies, still commonplace, the Council favoured tax reduction to improve business climate and attracting companies to relocate. Initial efforts emphasized the positive attributes of the region in comparison to other parts of the country through a public relations and publicity strategy.[6] However, the effort to attract branch plants failed. New England was too far from sources of raw materials and distribution networks to be an attractive location.

The Turn to Knowledge-based Economic Development

When conventional approaches failed, the Council explored a series of alternatives based on the knowledge resources of the region. The focus gradually shifted from

[6] More than six decades later, the New York Academy of Sciences pursued a similar strategy, developing an information campaign through publication of a Newsletter *Tri-State Trends*, drawing together data on the advantages of the New York metropolitan region. In this instance the publicity campaign focused on the attributes available for development of high tech industry. Nevertheless, short of more concrete steps, the Newsletters had little effect. In this instance, there was a lack of credible leadership to move the organizing effort to the next stage of development (Indergaard, 2004).

incrementally improving existing firms to discontinuously creating new industries. The Council early recognized that a concentration of academic and industrial research laboratories was New England's comparative advantage. The initial idea was to encourage small firms to conduct R&D themselves or contract with consulting firms and universities for assistance. It was soon realized, however, that these firms had declined too far and were lacking sufficient resources to revive themselves, even with assistance.

The Council's "New Products" committee, established to assist existing firms, turned to the more far-reaching idea that New England's research intensive universities could substitute for the natural resources that the region lacked. MIT President Compton, a committee member, extrapolated instances of firm formation by MIT professors into a vision for a new wave of technical industry. Beyond respect for his personal qualities and scientific achievements, his prestige as head of MIT as well as pride in the regions educational and research institutions, gained Compton an audience for his ideas. This receptivity was lacking on the national level where too much technology, and invention of labour saving devices, was blamed for causing the depression.

Much of the model of university based economic development was derived from the activities of Vannevar Bush, an electrical engineering professor and then Dean and Vice President of MIT. Bush was a prototypical entrepreneurial academic, combining in a very effective manner both intellectual and commercial interests in the course of his career. As a young academic, Bush learned that a patent he obtained secured legal rights but was no guarantee of profit. He learned from consultancy that if existing firms did not take up an idea then it was necessary to found a firm to realize it (Bush, 1970).

The Invention of the Venture Capital Firm

Although New England had capital and technology, it lacked a systematic methodology for firm formation. The strategy that evolved was based on a synthesis of university-business-government elements into a venture capital instrument: government changing investment rules; the university providing technology, human resources and capital to form new firms and business providing capital and legitimation to the new venture entity.

[7] Immediately after the war, Compton organized a consortium of universities, investment banks and insurance companies to found the first venture capital firm, American Research and Development (ARD) through sale of equity (stock) in the firm.

The organizational design and staffing of the project were derived from MIT and Harvard Business School. The elements included (1) *a search mechanism,* recent graduates of MIT, who followed up leads and walked the corridors as Technology Scouts to identify promising technologies; (2) *an evaluation procedure,* an advisory board of senior MIT professors that assessed technologies and provided leads to promising projects; (3) *business development capability,* recent graduates of Harvard Business School, who provided business advice as Consultants and monitored the development of the companies; (4) *leadership and networking expertise,* the head of the venture firm, intervened in client firm crises and linked the venture firm with academic, financial and policy networks. [8]

Technological opportunities were enhanced by World War II R&D projects, focused at universities, and expanded after the war into civilian as well as military fields (Bush, 1945). ARD's initial success, after a decade of investments, was the Digital Equipment Corporation (DEC), based on a Navy research project to develop a pilot training device. Although not completed in time for war-time use, the computer aspect of the project was supported after the war by the Air Force research agency as a radar control device. The Air Force eventually dropped the project but it was far enough along that it could be commercialized, initially as a circuit board, and then as a full fledged computer.

.

Driven by DEC's success, the venture firm was transformed from a pro-bono regional development corporation into a partnership for the benefit of its managers and investors. The venture capital model took its contemporary format after $400 million of DEC stock was distributed to ARD's shareholders. MIT did not gain financially, having sold its

[7] The venture capital process had previously existed, in nucleo, in investments made by wealthy family groups that had begun to professionalize their investment decision-making process by hiring staff to vet and monitor projects.
[8] The first head of ARD was Georges Doriot, a Harvard Business School professor with a unique interest in entrepreneurship at the time.

ARD stock before this windfall. Nor did MIT's direct role in regional development postdate the Compton era.

Broadening the Academic and Commercial Base

MIT and Harvard's role in the second wave of high tech firm-formation in the 1980s was based on the two schools early commitment to molecular biology. The academics involved in this new field were aware of its practical implications and were receptive to venture capitalists' proposals to create biotechnology companies. The entrepreneurial regional infrastructure that had been created during the early post-war supported these firm formation projects.

The expansion of the Boston biotechnology cluster built upon a broad academic base, not only MIT and Harvard, but emerging research universities, like Boston University and the University of Massachusetts, Boston. [9] These schools built up research capabilities in response to the emergence of the bio-tech cluster.[10] On the other hand, the mini-computer cluster grew apart from its academic source (Kidder, 1987). Indeed, one hypothesis to explain these firms decline was their relative isolation from academia.

There was an epistemological and normative break between the mini-computer and biotechnology eras. In contrast to the mini-computer experience, the Boston bio-tech cluster exemplifies three positive characteristics of a science city: (1) firms locating close to universities to encourage interaction of the cluster with its academic source (Smith-Doerr, 2004); (2) a reciprocal process of regional and academic growth occurring in tandem; and (3) a flow of polyvalent knowledge through collaborative projects, with multiple links between academic research groups and firms mediated by university technology transfer offices and conflict of interest guidelines.

---

[9] Brandeis University is an intermediate case in the time scale with strong, albeit relatively small, research groups in comparison to the larger schools in the area. Although it had small graduate programs almost from its inception in 1948, Brandeis has been better known as a liberal arts college. However, its research strengths were recently recognized in a study that, controlling for size of programs, placed Brandeis in the top tier of US universities.

[10] U. Mass Boston, a relatively recent entrant to graduate education, adopted a niche strategy of developing fields that other area schools had neglected, like gerontology, and high demand areas, like biotechnology, where there was space for several universities.

Close ties typically persist between the firm and the research group that incubated the proto-firm (Guaranys, undated). During an interim period, conflicts often emerge between researchers with conflicting economic interests and epistemological standpoints. For example, while Google was incubating within the Digital Library project at Stanford, researchers with divergent economic interests stopped talking to each other about "search" while those with no economic interest were temporarily alienated from their colleagues. The founders took a leave of absence from the Ph.D. Program, but their professor is a Google consultant and the algorithm is dissertation quality (Paepecke, 2005). The Engineering School has since worked out procedures to encourage firm founders to complete their degrees. A balance between separation and integration was found as people become more experienced in making the transition from 'lab to market' and back again. [11]

The Transition from Route 128 to Silicon Valley

Technical firm formation began to generate regional economic effects first in Boston and then in northern California. Although these effects were not unknown before the war, the increased scale of research speeded up the process of science-based innovation and made it more noticeable. This visibility was reflected in names such as Route 128, after the mini-computer complex that had followed from DEC's success and Silicon Valley, representing the semi-conductor firms stimulated by government procurement for military and space activities (Moore and Davis, 2004).

Firms based on academic work in applied physics like Hewlett Packard, had been founded before the war, or like Varian, just afterwards (Kenney, 2000). As these firms grew, they developed technically skilled managers who were available to organize the next wave of firms. Although new companies were typically founded by technical people; they brought in experienced people from older firms to help manage their growth.

[11] See Ylijoki, Oili-Helena 2003. "Contested identities and moral orders in academia" for an analysis of the conflict between various academic narratives at a university in transition.

Successive waves of firms followed this pattern, for example, in the 80's the young founders of Apple hired an experienced executive who had retired early from the semi-conductor industry.[12]

The semiconductor industry also provided a base for the next stage in organizational development of the Valley, the establishment of a formal venture capital industry. The venture firm began its transition in Boston to the contemporary model of time-limited funds, subscribed to by universities, insurance companies and pension funds, and reached its apotheosis in California.

From Informal Networks to Formal Organizations

Informal relations characterized the early development of both regions while more formal efforts arose in crises brought about by economic downturns and the need to renew the region's economy. Informal networking occurred in Boston in connection with the founding of MIT. A two brother academic industry link, a businessperson and an academic, were the nucleus of a lobbying effort that brought the academic brother's concept for a technological university to the attention of the business community, which provided some funds, and the Massachusetts legislature, which turned over 30% of the state's land grant to the new university (Etzkowitz, 2002).

University-Industry relationships supported a few graduate students before the war at Stanford. Fred Terman, electrical engineering Professor and then Dean of Engineering and Provost, maintained a network of local technical firms into which he inserted new firms founded by his students (Williams, 1998). His network also extended to national firms with Stanford ties, like ITT, where an alumnus was director of research. ITT provided Terman with several graduate fellowships to support students in exchange for the rights to the intellectual property that he generated from his research (Buttner, 1938).

---

[12] The growth of these firms was also facilitated by community colleges, the third and lowest tier of the California Higher Education System. For example, the Computer Science Department at De Anza College in the Foothills Community College District consisted of a relatively few permanent staff, greatly expanded by adjuncts hired from industry. In addition to the well known story of importing human capital from abroad, a broad range of local persons, from high-school dropouts to literature PhD's, were retrained as computer programmers.

The ITT connection provided a relatively stable base since a certain number of disclosures per annum were expected by contract and Terman was a prolific inventor. In effect, Terman ran a one person technology licensing program from his faculty office.

The experience of the 2nd World War, with academic researchers from across the country brought together to a few sites and provided with enormous resources, transformed American academia and especially Stanford, a school that eagerly adopted the new model of well funded polyvalent research. As Terman put it, “At Stanford I have been interested in building up the scientific level of the engineering faculty, and in developing a program of government sponsored research built around really fundamental scientific activities, not just advanced development of semi-industrial character.” After the war, Terman brought back contacts that he had made as director of the Radar Countermeasures Lab at Harvard and attracted significant defence research support to Stanford despite the university not having a major war-time lab.

The organization of academic research was transformed by the funding increase. The pre-war model was based on faculty student dyads, mostly at the Masters level, with occasional triads like Terman, Hewlett and Packard. However, there were often gaps in support. A student might take a job until support reappeared and they could return to finish their degree. The post-war academic model was the research centre, with permanent staff, supporting research groups composed of faculty, graduate students, and post-doctoral fellows. Some centres became departments as new academic disciplines were created such as applied physics and computer science.

A broad research focus led to the development of new industries as well as advances within existing firms. Combining practical and theoretical work, military research provided a massively expanded base for the development of the Boston and Silicon Valley science cities. In the early post war Terman described himself as the “…administrator of a large program of graduate study and about a million dollars’ worth of contracts for basic research in electronics, engineering mechanics and other fields”

(Terman, 1947a). Even new fellowships, provided by growing firms like Hewlett Packard, paled in comparison to federal support.

The Silicon Valley Ecosystem

The contemporary “Silicon Valley ecosystem,” by analogy with the biological schema of location of a variety of species in a mutually supportive environment, is based upon a formula for translating ideas into businesses. In addition to venture firms themselves, the ecosystem includes successful entrepreneurs, representing start-up management expertise, banks and the financial arms of large corporations as sources of co-financing, university professors and technology transfer offices as sources of new technologies for firms and law firms as gatekeepers between entrepreneurs and investment opportunities.

Although there are notable exceptions, Silicon Valley venture firms rarely invest at the so-called seed stage. Such funds are expected to come from associates of the firm-founders, the so-called “fff” friends, families and fools. Even angel investors typically do not invest at the earliest stages of firm formation. They usually want to see a customer and revenues before they are willing to commit funds. They are business persons and expect to use business, not technical, criteria in evaluating investment prospects. Business angels typically do not view universities as a source of investments and are not usually in touch with university technology transfer offices (Frick, 2005).

Firm formation from academia in Silicon Valley is informally incubated in research labs and university housing. The gap in the early stages of financing a new firm from university originated technology has been partially filled by a previous generation of academics, who have earned funds from firm formation, as consultants or during leaves of absence, and by graduates who have become successful entrepreneurs. These “science angels” combine an understanding of the technology and its business potential given their academic and entrepreneurial experience. They may invest despite lack of revenues, customers and even a business model, the traditional signals of success.

From “Ecosystem” to “Planetary System”

Silicon Valley has been defined as a new type of industrial environment where informal networks, among individuals sharing a common commitment to a technical area transcend the firm. Technical professionals exchanging ideas at a local bar, leaving a firm one day for employment at another, distinguished Silicon Valley from older industrial regions characterized by organizations with well defined boundaries (Saxenian, 1994).

Silicon Valley is evolving from an ecosystem of flat networks to a “Planetary system” of powerful entities with strong gravitational fields. Employees of some firms are under strict guidance not to speak about their technical work (Gebratsadek, 2005, Buyukkoten, 2005). In this mature innovation environment, older multi-national corporations, like Siemens, or new ones that have grown quickly like Google are creating a new, or at least more overt, centralizing dynamic. For example, Symantec, headquartered in Los Angeles, maintains a unit in Silicon Valley to draw local start-ups into its orbit while start-ups in the search space orient themselves toward Google and Yahoo in hopes of being acquired (Engel, 2005). Networks persist as routes to “gatekeepers” of angel networks and venture capital firms for newcomers and from academic entrepreneurs to venture capitalists and angels on behalf of their students (Etzkowitz and Picque, 2005).

“Planets” pull weak, yet promising, start-ups and niche organizations into their gravitational field as satellites. The remit of the Siemens Business Development Unit located in Berkeley is to identify technologies relevant to Siemen’s and access it either by hiring the inventor, where possible, or by offering to support a start-up. Siemen’s takes the angel investor/venture capitalist role in order to appear in a familiar guise to technology inventors who are more likely to be looking for funds for their start-up than seeking a position as an employee of a large firm (Hauser, 2005). The Stanford University Office of Technology Licensing undertakes projects on behalf of small non-profit research organizations in the Bay area. The Stanford “brand” legitimates a technology to potential investors.

Silicon Valley is perhaps the first high-tech region with multiple interacting technology bases, interconnected through links between “planets” and “networks.” The Director of the Siemens Business Unit, next to Berkeley, is at Stanford once a week. Nevertheless, gaps have emerged between formerly close partners. Planets, like Stanford University and Hewlett Packard, have drawn apart even though they are physically close. The director of university relations at HP suggests that “start-up fever” among faculty and students, has created a cultural divide with a mature corporation. HP is currently reconnecting to Stanford at several levels: individual faculty members, the Office of Technology Licensing and with the senior administration to jointly seek large scale government research projects.

The Global Dynamics of Regional Innovation

Silicon Valley is a hub for world-wide technology and capital flows, with imports and exports of human, financial and intellectual capital. The in-migration of technical talent and its movement into entrepreneurial roles is followed by out-migration as entrepreneurs return home to countries now able to support technical entrepreneurship (Saxenian, 1999). The Valley also pulls innovations from elsewhere into its orbit (Financial Times, 2005). Taiwanese firms founded by Silicon Valley alumni import technology from the Valley and manufacture in Taiwan to take advantage of lower costs. Israeli software firms export technology, developing in Israel and producing in the Valley to reach a broader market. Venture firms representing capital from abroad locate in Palo Alto to facilitate these interactions (Shalon, 2005).

A succession of high growth firms have been created in a series of industries. Bangalore and other regions are developing innovation capabilities but at present the Indian software region lacks the highly developed research, if not the training capacities, of Valley universities. On the other hand, the global growth of technology opportunities and the explosive growth of venture capital, beyond what can be profitably invested locally, is making the so-called “two hours drive time” rule to monitor an investment obsolete as Silicon Valley VC’s seek opportunities like Skype and Baidu, worldwide.

A concentration of venture capital and managerial talent with technical and business skills seeks firm formation and growth opportunities. Silicon Valley and Stanford "alumni," both academic and business persons, have brought the model back home. The origins of Chalmers Innovation, a network of incubation and entrepreneurship programs at a leading Swedish Technological University, can be traced to the initiative of a professor who spent a sabbatical at Stanford. A similar dynamic in biotechnology occurred in Helsinki.

The scale and scope of entrepreneurial resources in a single region makes the Valley unique. Silicon Valley has spread to both sides of the Bay, from above Berkeley to below San Jose. [13] This phenomenon has not been seen since Thomas Edison spun off a series of industries from his lab in Menlo Park, New Jersey. Seattle has a single high growth firm in a new industry; Northern New Jersey has a group of large research-based firms in a mature industry and Cambridge U.K. has a series of niche high-tech firms (Koepp, 2002).

Regional Renewal

In recent years, Boston and Silicon Valley have suffered downturns and been renewed through follow-on cooperative efforts, creating successive waves of firm-formation based on emerging technological paradigms (Bathelt, 2001). Despite evident success, the model is cyclical and subject to severe disruption. Firms typically become embedded in a particular technological paradigm and focus on working out its potential. They are rarely able to make the shift to a radical alternative and are merged into oblivion as their technological trajectory winds down. DEC, the progenitor of the Route 128 mini-computer industry disappeared into Compaq, with the decline of its core business (and Compaq then into HP). DEC had the capabilities but not the vision to enter the micro-computer industry at an early stage when it might have been a credible competitor.

[13] The Glasgow/Edinburgh/Newcastle/Durham/York (GENDY) Corridors, like the ORESUND cross border region of Copenhagen/Skane, has some characteristics of an emerging Valley. There are live networks between some universities, nascent networks among others, and doubtless other phenomena that could be mapped and built upon. GENDY is a hypothesis to make Science Cities into a greater whole. For example, ORESUND cluster organizations, like the Medicon Valley Academy, link firms and universities in emerging technology fields.

Silicon Valley and other technology conurbations appear to be solely “private” entities in the upturn but their “public” character is revealed in the downturn when laissez-faire models are deemed inadequate. A Science City is constructed by a variety of actors, typically including a double helix of industry and university and a triple helix of government, industry and university in various stages. Representatives of these groups play the role of ‘Innovation Organiser’ in designing new initiatives to foster economic and social development. Such groups typically have a spatial dimension that is regional in nature even though it may transcend previous regional definitions based on topographical, national or cultural factors (Markusen and Hall, 1985).

Collaborative efforts to create new technological paradigms emerged in Silicon Valley during the downturn of the early 90’s and after the collapse of the Internet bubble in 2001. In the late 1970s and early 1980s, the Competitiveness Center of SRI International advised Midwestern states, with declining industries, how to organize regional groups to revive their economies.   These policy researchers brought their model home in the early 90’s and helped establish Joint Venture Silicon Valley (JVSV), bringing together high-tech company executives, local government officials and academics for a series of public meetings. Some ideas that came out of these discussions were then put into practice to develop new high- tech industry. One project, Smart Valley, for computer networks and information resources provided the groundwork for firm- formation.

A New Model of Funding S&T Infrastructure

Federal opposition to stem cell research provided the impetus to a California initiative utilizing the method of direct democracy in California’s Constitution. A coalition formed of patient support groups focused on a cure for diabetes, academic scientists who wished to pursue stem cell research and venture capitalists interested in the next wave of commercializable technology. An attorney, whose child suffered from diabetes and whose previous career involved the innovative use of public bonds to support the development of low cost housing, led the campaign. Proposition 71, passed in the 2004 election, provides 3 billion in debt financing to support stem cell research at the state’s public and private universities and investments in biotechnology firms[14]

California has taken a new departure in state S&T policy on the premise that intellectual infrastructure is now as secure an investment as physical infrastructure. The objective is to create a self generating system of S&T infrastructure support derived from procedures to build public infrastructure such as housing, roads and bridges. It is expected that the borrowed monies will be paid back out of the proceeds from intellectual property created from academic research and the equity generated in biotechnology firms. Federal programs that provide money to researchers and firms expect payback to government, only indirectly and in the long term, through increased tax revenues and job creation. The California experiment envisions a direct feedback loop between university, industry and government in the form of a virtuous circle of science-based economic development.

The Emergence of the Entrepreneurial University

An institution of medieval origins that played a supporting role in feudal and industrial society emerges as the key institution of knowledge-based society, playing a role in economic and social development as well as research and education. An entrepreneurial university rests on four pillars: (1) legal control over academic resources, including physical property in university lands and buildings and intellectual property emanating from research; (2) organizational capacity to transfer technology through patenting, licensing and incubation; (3) an entrepreneurial ethos among administrators, faculty and students and; (4) academic leadership able to formulate and implement a strategic vision.

The university is an especially propitious site for innovation. This is due to such basic features as its high rate of flow through of human capital in the form of students who are a continual source of potential inventors. The university is a natural incubator; providing a support structure for teachers and students, to initiate new ventures, intellectual, commercial and conjoint. The university is also a potential seedbed for new interdisciplinary scientific fields and new industrial sectors, each cross-fertilising the other. Given recognition that new interdisciplinary fields are the source of economic

[14] $3 billion is expected to become 6 billion through interest accrued.

growth and intellectual distinction, the push for change comes both from scholars seeking new areas in which to make their mark and from senior academic management seeking to develop new research fields with economic and scholarly potential.

The Field of the Triple Helix

Universities are rigid in many ways, with departmental and disciplinary structures resistant to change. Nevertheless, by their very nature, universities have great abilities for adaptation and change. Their educational function requires them to prepare students across a range of subject matters, and within those fields, maintain a diversity of topics. Of course, universities only more or less fit this model as some national academic systems are more specialized than others. Nevertheless, it is the diversification of the university that gives it its ability to create new fields by hybridizing old ones, drawing faculty with related interests together and hiring in new faculty to develop new areas.

On the other hand, a firm has the ability to focus resources and attention on a single goal or core ecompentency. (This ability to focus with single minded intensity is the virtue of a start-up firm, before it becomes diversified into the varied possibilities of its technology and business.) Firms have the ability to create new units rapidly whereas universities may have to wait for a change in academic generations unless a school is growing rapidly. The interdisciplinary research centre with its combination of faculty members and research associates, who function more like industrial researchers, represents a synthesis of these two approaches. Firms also take on academic attributes, for example, by recruiting post-doctoral fellows who spend a limited period of time with the company, making their contribution and moving on.

In recent decades, government has played an entrepreneurial role, revising the rules for interaction among the institutional spheres. For example, in the U.S. in 1980, and more recently in Japan and Denmark, government has transferred the intellectual property rights, deriving from its research funding, to universities in order to incentivize entrepreneurial behaviour. Government has also changed the rules for competition among firms in the U.S. It encourages companies to collaborate with each other, and with universities, in joint research and product development efforts through competitive grants programs and tax credits (Etzkowitz, Gulbrandsen and Levitt, 2000). Brazil has similarly incentivized multi-national firms to establish R&D labs in science parks adjacent to universities.

The Triple Helix Model

Derived from the Boston regional organizing experience in the 1930's and 40s, the triple helix model comprises three basic elements: first, a more prominent role for the university in innovation; second, a movement toward collaborative relationships among the three major institutional spheres in which innovation policy is increasingly an outcome of interaction among university, industry and government; thirdly, in addition to fulfilling their traditional functions, each institutional sphere also 'takes the role of the other' operating on a y axis of their new role as well as an x axis of their traditional function. Thus, academia is a source of firm-formation in addition to its traditional role as a provider of trained persons and research. Government helps to support the new developments through changes in the regulatory environment, tax incentives and provision of public venture capital (Eisinger, 1997). Industry takes the role of the university in developing training and research, often at the same high level as universities (Fusfeld, 1994).

The model was expanded through analysis of areas where the role of one sphere in innovation, either predominated or was lacking, such as the state in Eastern Europe before and after the Berlin Wall. Too much, or too little, government impeded innovation. The military regime in Brazil developed innovation capabilities that carried over into the democratic era. The emergence of an incubator movement from the academic opposition to the military regime exemplifies the transition from a top down to a bottom up triple helix in a developing country (Etzkowitz, Mello and Almeida, 2005).

Knowledge, Consensus and Innovation Spaces

A triple helix model of regional innovation can be conceptualized as a series of knowledge, consensus and innovation "spaces". The knowledge space consists of concentrations of related R&D activities in a local area that have been identified as a precursor to knowledge-based regional economic development. For example, the movement of research institutes from Mexico City after earthquakes provided other Mexican regions with research capacity that is being applied to local problems (Casas, et.al. 2000).

The location of academic research was formerly uncontroversial since results were available everywhere through publication. As the economic implications of research, arise ever closer in time to the making of a discovery, the location of research becomes a political issue with regional relevance. Regions with exrensive research resources conflict with those that wish to develop similar strengths, creating pressures to expand research funding, such as the recent doubling of the NIH budget.

The consensus space brings together persons from different perspectives (academic, public, private) to generate new ideas. Joint Venture Silicon Valley (JVSV) played this role through open brainstorming sessions (Henton, 1994). The New York Academy of Science hosted a similar series of invited meetings during the mid 1990's. The Innovation Space is where the goals articulated in the Consensus space are realized. A new organizational mechanism may be invented such as the venture capital firm or a political instrument, like the California Proposition, may be creatively adapted. The infrastructure bond may be turned to a new use or the broader potential of an organizational innovation, such the incubator, may be realized.

Conclusion: Making Science Cities

We have viewed two prototypical science cities at different phases of their development. We began our discussion with the Boston regions' response to a grave economic crisis in the early 20th century in which it lost much of its economic base. Nevertheless, the region's academic base remained strong and even grew, in part, based upon support from outside the region as its universities were viewed as a national resource. For example, during the financial crisis that MIT experienced after World War One, help came from George Eastman, head of the Kodak Corporation who viewed MIT as a significant resource of people and ideas for his firm. The financial base of the region also remained strong although funds from previous economic success were loaned to corporations largely located elsewhere. The region also had a cohesive leadership structure that focused its attention on the potential for science-based economic growth.

As a developing region in the early 20th century, Santa Clara County lacked the accumulated resources of financial and social capital available to Boston. Nevertheless, university-industry cooperation was strong and provided a base to initiate the development process. Government became important during the post-war through federal grants and contracts that Stanford, and the early generation of semi-conductor firms, were well positioned to capture. Although the organizational infrastructure of the Valley was relatively weak; its loose networking mode of operation was a virtue in the boom era. Formal structures have been created, linking university, industry and government actors, to address downturns.

Other areas such as New York and Chicago had research intensive universities but not the local leadership to bring together resources to translate research success into economic growth, at least until quite recently. San Diego is another growing success case in which the effort to create a great science-based university has been the basis of a strategy to generate a local science-based industry in bio-technology. North Carolina's Research Triangle is much better known, but it has largely relied on attracting branches of national laboratories and multi-national firms. Such a strategy can jump start a region but without an entrepreneurial university it is difficult to make such an area self-sustaining (Lugar, 1994; Tournatzky and Gray, 2003).

The long-term criteria for success of a Science City are not only creation of a cluster of high-tech firms but the ability to regenerate itself as earlier successes are superseded. Relatively few regions have developed self-renewing capabilities. Strong conservative forces, typically emanating from large firms in existing industries, and their academic and government supporters, subsume much of the resources needed to make the transition. Beyond research capacity in emerging and interdisciplinary fields with potential for commercialization is the capability to effectively utilize these knowledge resources. This innovation capacity is largely dependent upon the network of public/private entities that can provide firm-formation expertise, gap funding, seed capital etc.

The project to create a knowledge-based region typically relies on expanding the capacities of universities or even founding new academic institutions for this purpose as has been done in San Diego and Merced, California. The university, however, usually acts as part of a broader configuration and when it fails to play a regional role it is often because a broader institutional coalition is lacking (Feldman, 2003). A culture of entrepreneurship within academia is enhanced by explicit transfer mechanisms and informal networks linking new entrepreneurs with previously successful mentors.

Emerging technology regions emulate these characteristics through programmatic intervention even as organizational entrepreneurs, such as founders of angel networks in Silicon Valley, franchise their models to other regions (Williams, 2005). Imported models are typically reinvented to fit the local context. After several failures, Israel's "Yozma" Public/private venture capital firm jump-started that country's venture capital industry. The broader potential of the incubator model, beyond high-tech-firms, was realized in Brazil as an educational format for co-operatives to create jobs for the unemployed (Etzkowitz, Mello and Almeida, 2005.

Academic advance and regional growth are mutually supportive goals. A region with a cluster of firms, rooted in a particular technological paradigm, is in danger of decline once that paradigm runs out. The need to periodically renew the technological capabilities of a region leads government, as well as companies and universities themselves, to explore ways for knowledge producing institutions to make a greater contribution to the economy and society (Etzkowitz and Klofsten, 2005). Some observers hold that Silicon Valley and Boston's Route 128 are unique and spontaneous developments (Dorfman, 1983). We argue to the contrary that the conditions for creating continuous high-tech social and economic growth can be identified and traced to specific organizational initiatives that have much in common.

References

Abir-Am, Pnina. "The discourse of physical power and biological knowledge in the 1930s: A reappraisal of the Rockefeller Foundation's 'policy' in molecular biology." Social Studies of Science 12 (1982): 341-382.

Bathelt, Harald. 2001. Regional competence and economic recovery: divergent growth paths in Boston's high technology economy Entrepreneurship & Regional Development. Volume 13, Number 4 October Pp. 287 – 314

Bush, Vannevar. 1970. Pieces of the Action. New York: Morrow

Bush, Vannevar. 1945. Science: the Endless Frontier. Washington DC: US Government Printing Office

Buttner, H.J. 1938. IT&T 67 Broad St. New York City, Letter to Frederick Terman 15 December. Stanford University Archives, Terman Papers, SC160 Series II Box 10 Folder 1

Buyukkoten, Orkut. 2005. Engineer, Google, Interview with Henry Etzkowitz, July

Casas, Rosalba and R. de Gortari and M. Santos. 2000. The building of knowledge spaces in Mexico: a regional approach to networking, Research Policy.

Cooke, P. 2002. Presentation Science Park Plenary Triple Helix IV Conference Copenhagen

Dorfman, 1983. Route 128: The Development of a Regional High Technology Economy Research Policy

Eisinger, Peter. 1997. The Rise of the Entrepreneurial State. Madison: University of Wisconsin Press

Etzkowitz, Henry. 2002. MIT and the Rise of Entrepreneurial Science. London: Routledge

Etzkowitz, Henry, Magnus Gulbrandsen and Janet Levitt. 2000. Public Venture Capital. New York: Harcourt

Etzkowitz, Henry and Magnus Klofsten. 2005. The Innovating Region: Towards a theory of knowledge based regional development R&D Management.

Etzkowitz, Henry, Jose Mello and Mariza Almeida. 2005 Towards 'meta-innovation' in Brazil: The evolution of the incubator and the emergence of a triple helix Research Policy May

Etzkowitz, Henry and Josep Picque. 2005 Silicon Valley in Transition: From Networks to Gravitational Field. Work in Progress

Engel, Jerome. 2005. Director, Entrepreneurship Program, Haas School of Business, University of California, Berkeley. Personal Interview with Henry Etzkowitz and Josep Picque

Feldman, Maryann P. 2003. , "Entrepreneurship and American Research Universities: Evolution in Technology Transfer," in Hart, David M. (Ed.), The Emergence of Entrepreneurship Policy:

Governance, Start-ups, and Growth in the U.S Knowledge Economy, Cambridge: Cambridge University Press, pp. 92-112.

Frick, Robert Chairman, K.E.S. Management Company, Personal Interview with Henry Etzkowitz and Josep Picque St. Marys College CA, August, 2005

Fusfeld, Herbert. 1994. Industry's Future: Changing patterns of industrial research. American Chemical Society

Gebratsadek, Michael. 2005. Engineer, Symantek, Interview with Henry Etzkowitz, July

Guaranys, Lucia. Undated. "Research Groups in an Entrepreneurial University" Ph.D. dissertation in progress. COPPE, Federal University of Rio de Janeiro

Hauser, Stefan. 2005. President and CEO, Siemens Technology to Business Center, Personal Interview with Henry Etzkowitz and Josep Picque Berkeley CA, August,

Henton, Douglas. 1994 Interview with Henry Etzkowitz, June

Henton, Douglas and Melville J. Walesh. 2002Collaboration and innovation: the state of American regions _ HYPERLINK "http://www.ingentaconnect.com/content/ip/ihe;jsessionid=3n6wkodbpsskq.henrietta" \o "Industry and Higher Education" _Industry and Higher Education_, Volume 16, Number 1, 1 February, pp. 9-17(9)

Indergaard, Michael. 2004. Silicon Alley: The Rise and Fall of a New Media District. London: Routledge

Kidder, Tracy. 1997. Soul of a New Machine. New York: Random House

Kenney, Martin. 2000. Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region. Stanford: Stanford University Press

Koepp, Rob. 2002. Clusters of Creativity: Enduring Lessons on Innovation and Entrepreneurship from Silicon Valley and Europe's Silicon Fen. New York: John Wiley

Lugar, Michael. 1994. "Science and Technology in Regional Economic Development: The Role of Policy in Europe, Japan and the United States" Technology in Society Vol. 16 (1) pp. 9-33.

Markusen, Ann and Peter Hall. 1985. Silicon Landscapes. London: Unwin, Hyman

Moore, Gordon and Kevin Davis. 2004. Learning the Silicon Valley Way," in Bresnahan, Timothy and Alfonso Gambardella (Eds.), Building High Tech Clusters: Silicon Valley and Beyond, Cambridge: Cambridge University Press, pp. 7-39.

Paepecke, Andreas. 2005. Research Associate, Computer Science Department, Stanford University, Interview with Henry Etzkowitz, July

Rocco, Mikhail. 2001. Societal Implications of Nanoscience Washington DC NSF.

Rosenberg, David. 2001. Cloning Silicon Valley. New York: Prentice Hall

Rossiter, Margaret. 1973. Justus Liebig and Emergence of Agricultural Science in America New Haven: Yale University Press

Saperstein, Jeff and Daniel Rouach, Mary Harney. 2002. Creating Regional Wealth in the Innovation Economy: Models, Perspectives, and Best Practices. London: Financial Times

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

Saxenian, AnnaLee. 1999. Silicon Valley's New Immigrant Entrepreneurs. San Francisco: Public Policy Institute of California

Shalon, Ted. 2005. Shalon Venture Capital, Palo Alto. Interview with Henry Etzkowitz, March

Smith-Doerr, Laurel 2004. Women's Work: Gender Equality vs. Hierarchy in the Life Sciences Boulder CO: Lynne Rienner

Stokes, Donald. 1997. Pasteur's Quadrant: Basic Science and Technological Innovation. Washington D.C. The Brookings Institution

Terman, Frederick. 1947a. Letter to Robert Hatcher, US Naval Air Missile Test Center Stanford University Archives, Terman Papers Series 3 SC160 Box 61 Folder 24

Terman, Frederick. 1947b. Letter to Henry Hartig. Stanford University Archives, Terman Papers Series 3 SC160 Box 61 Folder 24 December 15.

Tornatzky, Lou and Dennis Gray. 2003. Innovation U: New University Roles in a Knowledge Economy Southern Regional Council

Williams, James. 1998. "Frederick E. Terman and the Rise of Silicon Valley" International Journal of Technology Management Vol. 216. No. 8 pp. 751-760

Williams, Randy. 2005. Founder of Keretsu Angel Network, Interview with Henry Etzkowitz and Josep Picque, August.