Silicon Valley: The Sustainability of an Innovative Region[1]

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An entrepreneurially oriented educational institution that transfers existing knowledge and/or creates new knowledge has the capacity to generate significant economic growth. This is the case of Stanford University, which had a key role in the development of Silicon Valley, reinforced by government support that made it possible for the region to become a world innovation hub, attracting and circulating talent and technology, internationally. Human capital development and attraction is the most important factor for Silicon Valley's success. However, the increasing dependence of Silicon Valley on external sources of human capital and technological innovation is a potential Achilles' Heel, if competitive regions achieve "stickiness" and retain these assets.

Key Words: Silicon Valley, Entrepreneurial University, Regional Innovation, Knowledge-based development, Triple Helix.

1. Introduction

Silicon Valley is a regional innovation icon that attracts researchers and policy-makers from across the world, seeking to understand and emulate its success. Streams of visitors in recent decades, including Presidents de Gaulle, Mitterand and Medvedev, have made the pilgrimage to this secular shrine of knowledge-based innovation. Each brought home an interpretation of the Valley that accelerated the development of incubators, science parks and technopoles as catalysts of high-tech clusters and entrepreneurship (Rosenberg, 2001). The design principles of such innovation-support mechanisms are well known and easy to imitate, but the ingredients for their success are more elusive. Visiting an exemplary high-tech scene like Silicon Valley may not reveal the secret of its growth; rather, that key is to be found in the analysis of its origin and development.

Behind contemporary Silicon Valley, where success, as well as failure, is celebrated

[1] The author wishes to express thanks to Dr. Marina Ranga for insightful advice on the organization and development of this version. Earlier versions were presented as Keynote Address to the First Science City Conference, York, U.K. Oct. 2005 to the conference on "Cluster Policies" at the Institute for Entrepreneurship, Audencia Nantes School of Management, Nantes, France, Oct. 2009 and the "Commercialising University Research Workshop," University of London Birkbeck, Centre for Innovation, 23-24 Oct. 2011.

as a learning experience, there is a history of indigenous academic entrepreneurship and government-supported R&D, as well as importation and reinterpretation of ecosystem elements like the venture capital firm. Located on a pristine site surrounded by thousands of acres of scrub where valley turned to hills, Stanford took a proactive stance in creating industry to support academic development from its 1891 founding. Stanford looked to MIT as a model, although the industrial and technological environment in which the two schools originated differed significantly. MIT was built upon a manufacturing industrial base that provided support for its founding in 1862, in order to infuse research into local textile, leather and metalworking industries and enhance their technological capacity. However, by the time MIT developed research capabilities several decades later, these industries had declined or left the region. MIT instead became an incubator of new firms. Stanford and MIT were both committed to an endogenous strategy of encouraging firm-formation from academic knowledge.

The triple helix model of knowledge-based regional development derived from MIT's role in developing a strategy for the renewal of New England during the great depression of the 1930's and was implemented during the early post-war through the invention of hybrid organizations such as the venture capital firm (Etzkowitz, 2002). The strategy was then transferred to northern California where it reinforced an independently originated process of knowledge-based economic and social development.

Silicon Valley emerged as a result of Stanford University's development strategy as an entrepreneurial university engaged with industry and government that also made Stanford a world-class institution. Silicon Valley's rise was supported by double helix university-industry and government-university interactions that converged into triple helix university-industry-government relationships. The Valley has expanded from a local generator of new technologies and industries into the key node of a global network, with multi-national firms, countries, regions and universities maintaining outposts to market or source advanced technologies.

The paper outline is organized as follows: section 2 gives a description of the methodological approach of the paper. Sections 3 to 7 delineate a model of Silicon Valley's development derived from a historical analysis of region and comparisons on specific issues to selected regions in the world, such as Santa Rita do Sapulcai and

Porto Alegre, Brazil, Linkoping, Sweden and Boston, US. Section 8 concludes the paper with an analysis of Silicon Valley's sustainability.

2. Method

This paper utilises archival and interview materials drawn from research conducted at Stanford University, including participant observation at the Office of Technology Licensing (OTL) as well as interviews at universities, science parks and incubator facilities in Brazil, Sweden, and Finland[2]. These studies on the entrepreneurial university and regional innovation have been carried out from the mid 1980's to the present.

In this paper, we propose a five-phase model of Silicon Valley's development including:

(i) *Origin*: developing the capacity to create high-tech firms through knowledge and technology transfer, university-industry interactions and research;

ii) *Aggregation*: grouping these high-tech firms into a significant cluster with open lateral networks;

(iii) *Expansion*: growth of some cluster firms into large hierarchical organizations, in parallel with large domestic and foreign technology firms from elsewhere establishing R&D units in the Valley, along with a growing start-up dynamic;

(iv) Efflorescence: a continuation of the above phases and emergence of multiple interacting high-tech platforms in the region, at various growth stages, along with an influx of technology and entrepreneurs; and

(v) Renewal: moving from one technological paradigm to another as the cluster declines, beginning the start-up process over again with triple helix interactions emerging to solve problems and taking regional development forward.[3]

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[2] Some of these investigations were supported by the US National Science Foundation (History and Philosophy of Science, Technology, Values and Society and Geography Programs).

[3] This model draws on a four-stage model of regional growth and renewal developed by Etzkowitz and Klofsten (2005): (i) Incipient, creating the idea for a new regional development model; (ii) Implementation, starting new activities and developing infrastructure; (iii) Consolidation and adjustment, integration of activities to improve the efficiency of the infrastructure; (iv) Self-sustaining growth, renew the system by identifying new areas of growth.

3. Phase one: Origin of Silicon Valley

Contrary to the vision of self-generation from apricot orchards in the so-called "Valley of Hearts Delight", Silicon Valley did not arise from a blank slate of a Greenfield agricultural region without previous industrial tradition. Indeed, a canning industry that grew from the need to move produce to distant markets was a source of mechanical engineering expertise, useful to an emerging electronics industry (Matthews, 2003). In contrast to Boston's technological focus derived from manufacturing, northern California's originated in the mining industry's moving water long distances and concentrating its force to separate ore.

The northern California gold mining experience provided "…a conceptual model for transmitting power long distances" (Williams, 1998: 172), followed by a hydroelectric industry that seeded technological development in long-distance electricity and radio wave transmission (Williams, 1997). Transcending distance provided an overarching paradigm that eventually led to the exploration of electronic solutions, similar to the problems of coal mining that provided the impetus to the development of the steam engine, thermodynamic theory and the industrial revolution in the North East UK.

The intersection of an "overcoming distance" technological paradigm and an older organizational pattern of small entrepreneur-run firms, characteristic of mid 19th century networks in the telegraphy industry, produced a unique regional innovation culture, before the ascendancy of large corporations. The Western Electric and General Electric Corporations dominated the East and Mid-west, but did not extend their reach to northern California in the late 19th and early 20th century. Technical work was organized in small-scale entrepreneurial forms, identified by Saxenian (1994) in postwar northern California, and earlier characteristic of the East and Midwest (Adams and Butler, 1999). Thus, pre-bureaucratic firms like Federal Telegraph, founded in 1909[4] and Eitel McCullough, founded in 1934, became the

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[4] Its founding name was the Poulson Wireless Telephone and Telegraph Company, after the Danish professor who invented and patented an "electric arc" device for wireless voice transmission. Cy Elwell, a Stanford engineering graduate, after evaluating the wireless technology of McCarty Wireless Telephone Company, a San Francisco firm founded in 1905 to commercialize a local invention,

organizational model for subsequent start-ups like Hewlett-Packard, begun as a partnership in 1939.

The networked Silicon Valley firm carried early 19th century practice forward in a niche where it had not been superseded by corporate practice. The region became a haven for independent inventors, who sought to develop their inventions outside of the purview of large corporations, such as Lee de Forest, who invented the audion and Philo Farnsworth, who made key television advances. Given the prevalence of an entrepreneurial organizational format in the region, it is not surprising that Shockley would return to Northern California, when he decided to leave Bell Labs to found an independent firm. Similar processes of splintering and regeneration occurred with the demise of Hybridtech in San Diego and Shockley Semiconductor in Silicon Valley, suggesting the efficacy of the start-up process, including its failures, for regional growth (Caspar, 2007).

Stanford's Knowledge Base for Spin-offs

From its inception Stanford University provided a knowledge base for spinning off new industries and firms as a source of regional development. At the turn of the century, Northern California was dependent on the East for electrical equipment. Stanford trained engineers configured and operated these technologies, but the region lacked its own technological industries. The School's founders believed that distinction could only be attained if it was surrounded by technology industry. Since that industry did not exist, it would have to be created. The base on which it could be built was the Engineering School itself. Putting their own resources behind this strategy, Stanford's first President and a few prominent faculty members invested in firms formed by recent graduates in the emerging electrical industry. In this stage, the Stanford Engineering School was a repository of trained people and existing technical knowledge that could be utilized for firm formation, even before the development of advanced research as a spin-off source. The importance of trained people as a source

decided that the Danish approach was superior, travelled to Copenhagen to obtain a license and returned with the equipment and two of Prof Poulsen's assistants to assist the transfer. Elwell demonstrated the Poulson device to his former teachers and the President of Stanford, who were sufficiently impressed to invest in the new firm together with Palo Alto business people (Morgan, 1967:41) of knowledge-based economic development is not necessarily related to a university only; it can also take place at the secondary level, as illustrated by the origins of Santa Rita do Sapulcai, Brazil's "Electronics Valley" (Box 1).

Box 1 – The Silicon Valley of Minas Gerais

A relatively isolated town of 30,000 in Minas Gerais, two hours drive from Sao Paulo is home to 160 electronics firms, focusing on telecommunications, but now diversifying to biomedical and other electronics application fields. The cluster's first firm was founded in 1978, but the cluster's origin is recognised as the founding in 1959 of a secondary technical school, focusing on electronics. The School was the brainchild of Sinha Moreira, a woman who had grown up in the region, but had travelled widely as an Ambassador's wife, including to post-war Japan, where she saw the role that technical schools were playing in the economic renewal of Japan. She believed that the same phenomenon could take place in her hometown and took the lead in founding the school. Now home to two universities, with PhD programmes and emerging research capabilities, the region's electronics industry was sourced in a secondary school, passing on existing textbook, device and tacit knowledge in the field, much as Homestead High School, in its electronics course-module, was doing for Steve Jobs in Cupertino. Similarly, De Anza College and the Foothills Community College district San Jose State University and other less well known schools than Stanford, played a role in training thousands of entry-level software engineers, but that role is an under-appreciated Silicon Valley asset.

The Minas Gerais high tech conurbation is estimated to be at the development level of early post-war Silicon Valley, before this label was affixed. The two clusters of electronics firms, built from and interacting with a knowledge resource have a rough comparability. Key differences reside in the level of knowledge resources (an emerging research university vs. a secondary technical school) and, most importantly, in the scale of government R&D resources committed to northern California, primarily in the postwar, at the instance of Stanford and at government's own initiative. Although the Santa Rita cluster developed an HDTV standard, the Brazilian government adopted a Japanese proposal, lacking confidence in locally originated technology at the time (Anonymous, 2011).

Contemporary teaching universities in many parts of the world play a similar role in their regions, taking steps to become entrepreneurial universities prior to, or simultaneously with, developing research capabilities. Problems and opportunities arising from these ventures often become the source of research questions that inspire individual academics to create niche research foci of local relevance that may later be generalised into fundamental research topics. The classic case is the agricultural researchers at mid-western state universities in the early 20th century, who, in attending to the problems of local agriculture, saw the potential for a more fundamental approach in genetics research and developed hybrid corn and other innovations (Griliches, 1998). There was no contradiction between meeting stakeholder needs and developing a fundamental line of research. Indeed the former task provided the necessary support for the latter endeavor.

Alternative Explanations of Silicon Valley's Origins

Various alternative explanations have been offered for the inception of Silicon Valley. Owens (2007) holds that the individualistic risk-taking culture inspired by the 1850's gold rush carried over into the generation of a technology cluster. However, there have been other "gold rushes" in Alaska and other parts of the world that did not lead to equivalent innovation complexes. Nor did a rush necessarily inspire an individualistic culture. Indeed, the Australian gold rush of the 1850's strengthened a culture of mate-ship and defiance of authority, forged in a pastoral "bush" wilderness, which has been a continuing influence, especially in facing wartime hardships from Gallipoli to Vietnam.

Nor did the Northern California technological firm founders of the early 20th century seem especially inspired by pecuniary considerations. Eitel, Litton, the Varian brothers, Hewlett and Packard, appeared to be motivated by the opportunity to practice their technical craft in an autonomous fashion, not wishing to work for large organizations, on the one hand, and committed to the region, on the other (Lecuyer, 2003). The Varians were particularly interested in establishing a community of like-minded technical persons, modeled on the utopian community in which they had been raised. Litton sold his company as it entered a high-growth phase and reestablished himself in the mountain community that was his dream location and inspired a cluster of small firms nearby his own. Of course, financial success was a prerequisite to attaining these objectives, but it did not seem to be the overriding motivation that it became for some in the postwar venture capital and dot com eras. The time gap between these stages is sufficiently long to suggest that we must seek other explanations than a "gold rush mentality" to explain the origins of Silicon Valley.

Another explanation for the cause of Silicon Valley's regional economic development could be the dense social capital networks emanating from a developed civil society, which have been used to explain the strength of traditional Italian clusters (Priore and Sabel, 1984). However, social capital in Silicon Valley was built on a different base:

the collaborative pursuit of innovation. As individuals came together to pursue joint projects, they created a web of ties over time that became the source for collaborators on future projects in an escalating spiral of innovation.

Individual inspiration is yet another explanation. According to Paul Krugman (1994: 227), “Silicon Valley is where it is because of the vision of Frederick Terman, vice president of Stanford, in supporting a few high-tech entrepreneurs in the 1940’s, forming the seed around which the famous high tech concentration crystallized. “ The Valley is thus held to exemplify the concept of “…path dependence---the powerful role of historical accident in determining the shape of the economy. “ But Terman was no “accident,” except perhaps in returning home to recuperate in California from illness, rather than staying on at MIT as an Assistant Professor, where he had been trained. Even as a significant figure in developing the technology cluster adjacent to Stanford, he was expanding upon and promoting a phenomenon that was already in motion when he joined the Stanford faculty scene as a newly graduated MIT PhD, who had been mentored by Vannevar Bush, the prototypical MIT academic entrepreneur.

4. Phase two: Aggregation

Encouraging spin-offs was a key part of Stanford’s academic development strategy. Federal Telegraph Corporation (FTC), founded in 1911 by graduates of Stanford University, assisted by investments by the President and prominent faculty members, was the flagship firm of Northern California’s nascent electronics technology cluster. However, after its takeover by ITT, FTC was moved East to Newark, New Jersey in 1930; it was unable to successfully challenge Radio Corporation of America’s (RCA) domination of the early electronics industry, given US government support for the “national champion.” Thus, the creation of a new wave of firms from Stanford in the late 1930’s, starting with Hewlett Packard, represented a second attempt to create a western electronics industry.

A technical substrate was available for an innovative engineering school to enhance with higher academic knowledge. Engineering School Dean, Terman’s academic development strategy in the 1930s had three key elements: 1) making close connections between science and engineering departments; 2) linking academic departments and local science-based firms and 3) concentrating resources on a few key research areas with both theoretical and practical potential. Terman included visits to area firms, such as H K, Eitel-McCullough, and Litton Engineering in student training. He encouraged electrical engineering students to appreciate commercial potential of electronic devices and work on multidisciplinary research projects. The flow of students went in both directions—towards industry and basic research disciplines, notably physics (Williams, 1998; Lecuyer, 2003). Stanford professors and their former students, in nearby firms and in the university, made a series of inventions in the late 1930's that took the local electronics industry to a new level (Norberg, 1976).

Interaction between firm and university in the early years of Silicon Valley created a common technological platform (e.g. electronics, microwave, radio). Terman operated in the context of a nascent high-tech cluster in the 1930's. He played a seminal role in expanding that cluster and deserves the title he has been given as 'father of Silicon Valley", but Terman built upon other's work. Cohen and Fields (1999) take the origin of this spiral to be "…the relationship between Stanford University and a small group of entrepreneurs during the late 1930's." This interactive dynamic has been traced back to the early 20th century and further specified as a two-way flow between Stanford and local technical firms (Lecuyer, 2003). However, the start-up dynamics was sourced in Stanford's academic development strategy of encouraging firm formation to make this interactive university-industry relationship possible.

A firm-formation process, moving across successive waves of technological opportunities, appearing in local research or, as with the transistor, imported from Bell Laboratories in New York and New Jersey, created the Silicon Valley phenomenon, with its organizational innovations such as the science park. Terman recognized the influence of MIT on his vision in his oft-quoted 1943 letter from Cambridge, MA, where he headed the Radar Countermeasures Lab at Harvard and was in a position to observe developments along the Charles River. In a letter to his friend, Stanford's treasurer, he predicted that if Stanford did not follow the MIT model of aggregating federal government research resources in the post-war, it would be relegated to the status of a teaching university, a Dartmouth College, in his words (Etzkowitz, 2002).

Realising the implications of unexpected positive results, and formalizing them, promoted Stanford's success. The science park is an unanticipated result of Stanford's effort to capitalize its extensive land holdings in the 1950's, intersecting with the emergence of science-based firms from academic research. Restricted from selling land by the terms of its endowment, the university leased lands to the developers of a shopping center. The university followed up this success with a plan for an industrial park. However, the firms that expressed interest were high-tech firms that had originated from the university. Recognizing the significance of this phenomenon, the university made R&D orientation and university links criteria for admission, thus inventing the concept of a science park (IASP, 2011). However, it was a decade-long process of encouraging firm formation from the university and interaction between the engineering school and local electronics firms that led to the creation of the park: the companies did not spring from the park, it was the other way around.

A felt need to counter Eastern domination of the field led competitors to band together for mutual assistance in a Western regional electronics association. Stanford University supported this effort, creating the Stanford Research Institute in 1946 to assist the industry, as well as build up the university's strength in the field by attracting government contracts. Government initiatives were crucial to Silicon Valley's development. Government procurement induced a learning curve in the nascent semiconductor industry and aeronautics, and space research facilities attracted firms to locate R&D and then production facilities in the region (Etzkowitz, 1984; Lowen, 1997). The visible presence of government has declined in Silicon Valley in recent years, but research largely sponsored from federal funds represents 30% of Stanford's 3.8 billion 2010-11 operating budget (Stanford, 2010).

The university served as a neutral ground, creating links among firms in cooperative arrangements, foreshadowing contemporary academic centres that include pre-competitive research, with early reports circulating freely between a university firm, often one derived from academia. The start-up dynamic was expanded, with Hewlett Packard and Varian Associates originating from academic research projects and training programmes. A cadre with technical and managerial skills was created that organized successive waves of firms, drawing upon people, like Mike Markkula, a semiconductor executive from a previous wave, to manage the growth of a personal computer firm like Apple, opening up a new niche that developed into a significant cluster (Freiberger and Swain, 1984). Technological advances realised at Xerox PARC, through the invention of the mouse and other elements of the personal computer, were synthesized into an attractive user-friendly package by Apple. This innovation extended the reach of the Valley from providing inputs into industrial processes and government projects to reaching end-users and consumers.

Integrating aspects of academic culture, the high-tech firm became a hybrid entity meeting the university that had integrated entrepreneurial elements halfway. Thus, the structure of work in the academic research group, with its unlimited hours focused on research goals, is echoed in the un-bounded hours of the start-up firm. The 9-5, 5 days a week time frame is superseded by a 24/7 mentality in which a project goal with a deadline and employees set free to find their own path to meet the goal replaces conventional supervisory management with self-management (Shih, 2002). "Project time" supersedes and overwhelms other forms of time organization as achieving the project goal becomes the over-riding objective. Individuals must be willing to give their life to the firm and therefore only persons able and willing to put aside other life goals are fit for the strictures of project time. "Whatever it takes" is a typical answer to the question of how many hours are devoted to work. Multiple temporal spheres, with parallel life activities, are reduced to one in the race for academic priority or product to market. The late Steve Jobs explained that one reason for arranging his biography to be written was to let his children know what he was doing when he was absent from their lives (Isaacson, 2011). The potential for high financial or reputational rewards, an ethic of "craftsmanship" and a desire to imbue oneself into a scientific discovery, new technology or device drives commitment. The intensity of this work model explains why many Silicon Valley job times may be relatively short with "sabbatical breaks" to take up other life interests sequentially rather than in parallel (Rao and Scaruffi 2010).

Behind innovations, like the Google search engine, there is typically an agglomeration of social, intellectual and financial capital. For example, Google originated from government-university collaboration, in this case the Defense Advanced Research Project Agency program in data mining and the Computer Science Department at Stanford University, with mid-wife assistance from Stanford's Office of Technology Licensing (OTL) (Meija, 2005). In addition, a "university angel," a serial entrepreneur in the Computer Science department recognized the commercial potential of the algorithm long before a business model had been inferred, invested and introduced the project to a venture capital firm.

5. Phase three: Expansion From Innovation Ecosystem to "Planetary System"

Innovative clusters in Silicon Valley developed a typical life course, originating in knowledge derived from academic research or R&D labs of large firms. They took shape as an interactive group of start-ups, a few of which attaining great success and at least partially detaching themselves from their cluster of origin to become an integrated multinational corporation, like Intel, and then returning to their cluster and academic bases to renew ties and acquire start-ups and advanced academic knowledge to improve their product lines and reinvigorate their knowledge bases. These processes took place in parallel, with innovative clusters, arising, declining and reviving, with many individual firms superseded in the process, their technologies outmoded, like SUN Microsystems workstations, and becoming acquired for their people as much as for their product line.

New technological paradigms emanating from academic research, like biotechnology, networking technology, from academic support structures and the transistor and integrated circuit from corporate R&D labs provided the base for a firm-formation dynamic that attained critical mass, exemplifying the "expansion phase". Experienced technical entrepreneurs were available, both from previous firm successes and failures, to provide so-called "adult supervision" for a new generation of start-ups. Matching experienced entrepreneurs with start-ups has become a Silicon Valley dating ritual, institutionalized in meetings and demo-days, catalogued in the Start-Up Digest calendar. A start-up culture, including recent graduates and long-term firm employees shape their networks of friends and acquaintances into proto-firms in academic research groups and existing firms, that then hive off into independent entities (Start-up Genome, 2011). Silicon Valley is unique in the large number of successful high-growth firms created since the late 1930s until present (see Table 1 below).

Table 1 - Silicon Valley Originated Fortune 500 Firms

Company	Fortune 500 Rank	Date Founded	Origination	2010 Employees (* 2011)	Market Value (millions)
Hewlett Packard	11	1939	Stanford	324,600	97,736
Apple	35	1976	Homebrew Computer Club (Met at Stanford)	49,400	323,866
Intel	56	1968	Spun off Fairchild Semiconductor	82,500	111,791
Cisco	62	1984	Stanford	71,825*	95,524
Google	92	1998	Stanford	28,768*	188,460
Oracle	96	1977	Begun from CIA work	108,429*	159,560
Applied Materials	259	1967		13,045	15,360
eBay	269	1995		17,700	41,430
Advanced Micro Devices	357	1969	Spun off Fairchild Semiconductor	11,100	3,140
Yahoo	365	1994	Stanford	13,600	20,430
Sanmina-SCI	366	1980		48,000	638,000
Symantec	382	1982	Stanford & NSF	18,600*	13,290
Agilent Technologies	419	1999	Spun off Hewlett-Packard	18,500	11,710
San Disk	468	1988	Former Intel Employees	3,469*	10,880

Source: compilation from literature by Michelle Baker

The proximate source of the Hewlett Packard, Apple and Google firms was collaboration between friends and colleagues, but these rested on a deeper structure of support. Thus, the initial Hewlett Packard product derived from a research project in the Stanford Engineering School mentored by their professor, Frederick Terman, which was itself the outcome of a tradition of university-industry interactions (Lecuyer, 2003). The Apple computer was based on a processor from a burgeoning semiconductor industry, whose development was facilitated by large-scale government procurement. Without the facilitative eco-system and collaborative environment of the Homebrew computer club, the resource of the SLAC (Stanford Linear Accelerator) Library and a contract from the Byte Shop, an early digital store, Apple Computer might have been stillborn or never born (Freiberger and Swain 1984). The search algorithm that became the basis of Google arose from a collaboration of two PhD students who met at the Stanford Computer Science Department, but was also the outcome of a DARPA (Defense Advanced Research Projects Agency) multi-million dollar data-mining project at several universities in which Page and Brin participated. These instances suggest the need to look beyond surface phenomenon for underlying causes and precipitating factors. A long-term perspective is required to achieve highly interactive business, government and university spheres in development of regional innovation clusters, rather than a mere physical facade.

Free-flowing industrial academic interchange in the early years of Stanford and MIT, with firms incubating in academic labs, was enhanced by formal organizational mechanisms, such as a Technology Transfer Office (TTO) and an Industrial Liaison Programme, to facilitate interchange. As an academic administrator put it, contemporary "MIT does not have the physical or intellectual infrastructure to support firm-formation inside academic labs." A Stanford administrator said, "We wouldn't do that here." Incubation in the lab in US academia was discouraged by "conflict of interest" concerns, but was recently legitimized in Brazil as an academic development and industrial innovation strategy (Box 2).

Box 2 – "Firm-in-the-lab"

In a reprise of MIT and Stanford's early history, the Brazilian Innovation Law of 2004 allows universities to sponsor conjoint academic lab/firms, realizing the utility of inducing permeability in universities to stimulate entrepreneurship. The Pontifical Catholic University of Rio Grande do Sul, an aspiring research and entrepreneurial university in Porto Alegre, has taken advantage of this provision to attract leading scholars from the neighbouring federal university who wish to start-up inside their research group. A husband and wife research team founded 4G, a research group located in the university's science park that is also a legal and functional firm. The members of the group (professors, research associates, post-graduate students etc.) divide their time between a basic research program and production activities. Research funding is provided by CNPQ, the national research council, while the so-called "Green and Yellow Fund," a federal research commercialization body, supports development work. Instead of duplicating facilities, as is typically required by US university conflict of interest rules, Brazilian law allows a 'confluence of interest' that is especially relevant to fields where theoretical knowledge and practical results are inextricably intertwined. The 'firm-in-a-lab' utilizes a bioreactor in a corner of the lab to make its product that is air freighted to customers in the San Diego biotechnology cluster.

Nevertheless, internally generated start-ups may happen without the direct involvement of the TTO, especially when intellectual property rights are not at stake. For example, a Stanford medical researcher, wound up her lab, took early retirement and used her final pay as start-up capital for a medical software simulation firm. Nurturing the early phase of a start-up in an academic research group occurs naturally, as group meetings generate ideas to realize the theoretical and practical implications of their findings, exemplified by some of the projects showcased at the StartX's Demo Day (McClure, 2011).[5] Faculty members and research associates as well as students, whether undergraduate and graduate, are members of some of the start-up teams supported by basic research funding in academic labs, especially in the medical school.[6] One team was applying for commercialisation funding from SBIR; another already had their product on the market in Apple stores in the U.S. and Europe as an IPad app, while still others have achieved seed funding or agreements to distribute their products through major firms.

A corollary of Silicon Valley's expansion phase is the partial replacement of lateral interactions by more hierarchical regimes. One iconic firm instituted a compartmentalized system with employees restricted to their areas by color-coded ID's. An employee of another iconic firm was happy to discuss his Stanford experience as long as the discussion did not extend into his new employer's technology. The freewheeling cross firm informal after hour's exchanges of an earlier era dampened as firms matured. However, a dynamic start-up culture has renewed the culture of free exchange, with its own collaborative formats of Hackathons, code camps and meet-ups, as well as traditional bar and coffee house conversations.

Older multinational corporations like Siemens, or new formations that have grown quickly like Google, create a centralizing dynamic, drawing start-ups into their gravitational field. For example, the remit of the Siemens Business Development Unit located in Berkeley is to identify technologies relevant to Siemens and hire the inventor or offer to support a start-up. Siemens takes the angel investor/venture capitalist role so as to appear in a familiar guise to entrepreneurs who are more likely

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[5] The recent Stanford graduate founders of StartX were respectively CEO and CTO of Business Association of Stanford Entrepreneurial Students (BASES) where they began their collaboration.
[6] Author interviews with firm-founders at "Demo Day" 8 September 2011

to be looking for funds for their start-up than seeking to become an employee of a large firm (Hauser, 2005). Symantec, headquartered in Los Angeles, maintains a unit in Silicon Valley to draw local start-ups into its universe while start-ups in the search space orient themselves toward Google and Yahoo in hopes of being acquired (Engel, 2005)

The key role of Stanford in the development of the region receded as high-tech firm development and entrepreneurship appeared to have an independent life of its own. To ensure renewal of its technological base, Silicon Valley needs the continuing inspiration of several great universities. The trustees of the University of California have recently called upon Silicon Valley firms to use some of the piles of cash they are sitting upon to make up for loss of state support of the university. There was no immediate response to this challenge.

6. Phase four: Efflorescence

Contemporary Silicon Valley is in an efflorescent phase, with a series of innovation clusters at various stages of development, crosscutting and hybridizing various technological fields. Such a generative phenomenon has not been seen since Thomas Edison spun off a series of industries from his lab in Menlo Park, New Jersey, which did not agglomerate locally. Seattle has Microsoft, a leading firm in a new industry; Northern New Jersey has a group of large research-based pharmaceutical firms in a mature industry and Cambridge U.K. has a series of niche high-tech firms (Koepp, 2002), but none of them has simultaneous, multiple clusters at various growth stages as Silicon Valley.

Simultaneous technological paradigms in play, from semi-conductors to social networking technologies, may mask downturns in Silicon Valley, as an upswing in one field may cover decline in another. For example, building upon microwave, semiconductor and electronics advances, an entirely new biotechnology cluster was created in Silicon Valley from academic research. It started with Stanford's Provost Terman, who realised the implications of the "double helix" discovery and encouraged development of chemistry fields that would prove crucial to the future development of a biotechnology industry. A similar development took place at the University of California, San Francisco and a few other universities that recognized the potential of the discovery. Building upon the idea of PhD student Peter Lobban, a collaboration between faculty members Cohen and Boyer at the two universities invented recombinant DNA, the key to realizing the practical potential of DNA that Watson and Crick foreshadowed in their seminal 1953 paper. Swanson, a venture capitalist, invited Cohen and Boyer to found Genentech, the progenitor firm of the regional biotech industry. As in Boston, a venture capital industry grew from successful development of a previous technological platform, semiconductors, and took the initiative in creating the new biotech industry. Government-supported academic research provided the substrate for both academic article production and firm formation. Stanford's TTO preached the gospel of the discovery's broad industrial potential to companies through its marketing efforts and hastened take-up (Feldman, 2005).

Nevertheless, the effects of the recession of the early 1990's, when the US was in danger of losing the semiconductor industry to Japan, were too strong to be hidden. Impelled by crisis, hostility towards government was put aside in the mid 1990's. The decline impelled a respected industrial leader to call together the region's business, academic and governmental leadership to found a regional organization: Joint Venture Silicon Valley (JVSV) bringing together local firms, governments and universities. A series of open brainstorming sessions were held that generated various ideas for renewal that were winnowed, following a venture capital approach, into a focus on networking technology (Henton, 1994; Miller, 1994). A highly individualistic entrepreneurial ideology had to be overcome to pursue collective action (Saxenian, 1990). An entrepreneurial region, with increasingly individualistically oriented firms, renewed its inter-firm network and its ties with academia and government. Nevertheless, the centripetal forces that hold the region together are still relatively weak, with little "top down" guidance, apart from specific technologically targeted federal Agency initiatives, e.g. DARPA's data mining and Energy ARPA's renewable energy projects (Youtie, 2010).

7. Phase five: Renewal

From the 17th century, Dutch East Indies Company ships brought the treasured goods of East Asia to a row of warehouses on Entrepot-dok Street in Amsterdam. The embarrassment of riches created a culture torn between frugality and conspicuous consumption, recession and extravagant growth, public austerity and private excess (Schama, 1987). Silicon Valley may be considered a contemporary “entrepot-dok”, a receiving point and marketplace for aspiring world-class entrepreneurs, technologies and business ideas. Silicon Valley has devolved from a regime of extensive public expenditures in the 20th century, creating its research, transportation and business infrastructure to the current context of public austerity and private excess. By the early 21st century, formerly modest suburban landscapes like Cupertino, the headquarters of Apple, have been transformed into upscale neighborhoods. The formerly well-resourced public education system has been starved for resources by a conservative anti-tax movement. The Valley still reaps the benefits of a previous era of public investment, but faces the danger of losing the ability to regenerate itself. What appears to be an independent self-sustaining and self-organising process, based on an “innovation eco-system” of law, accounting and head hunting firms, business angels and venture capitalists focused on generating start-ups, attracting neophyte entrepreneurs to Silicon Valley to gain access to their expertise (Munroe and Westerland. 2009) is actually a highly dependent enterprise.

The innovation eco-system has the appearance of an independent dynamic force, but is itself sustained by two pillars that are essential for its renewal: (i) university human capital production, and (ii) government- and large firm-supported research. Lacking these supports, the ecosystem is increasingly starved of oxygen and eventually loses momentum and may be unable to continue its growth trajectory. Without a renewal of public support and/or growth of private philanthropy, Silicon Valley will start to resemble aspiring high-tech regions attempting to create an innovation development strategy with a weak university and/or government support structure.

Peter Thiel, prominent Silicon Valley angel, and early financer of Facebook, in a talk to BASES, the Stanford student entrepreneurship club, recently recognized the essential role of government (Thiel, 2011). Reflecting upon the past decade of heavy venture capital investment in “Cleantech,” expected by many to be the next wave of technological innovation and firm success in the Valley, he said that it has achieved less than stellar results. Heretofore known as a typical Silicon Valley government skeptic, Thiel called for the US government to institute Five-Year Plans for technological development[7]. The underpinning of the venture capital industry by government funded R&D thus received its due as an essential basis for the inception of a new technological paradigm, rather than merely mining an old one.

8. Conclusion: Sustainability of Silicon Valley

Silicon Valley has gone farther and faster along the road to achieving a Knowledge Society, but similar dynamics may be identified in other regions. For example, the Boston region started a process of knowledge-based economic development earlier than Silicon Valley. Indeed key elements of the model were invented there, such as the venture capital firm and triple helix governance (Etzkowitz, 2002). Efflorescence was more limited, but the region demonstrated that it had a strong knowledge base and capacity to renew itself with a thriving biotechnology complex that attracted major pharmaceutical firms after the decline of the Route 128 mini-computer cluster (Cooke, 2001)[8].

Silicon Valley is an attractor of human, financial and intellectual capital, internationally[9], but it may lose its capacity to regenerate itself by becoming overly dependent upon the attraction of external human and intellectual capital for its sustainability. As successful entrepreneurs return to their home countries to help found new technology conurbations, a new generation of aspirants arrive in the Valley (Saxenian, 2007). For example, a Russian-originated firm seeks markets for 3D algorithms developed at a Siberian university (Uvarova, 2011); Catalonia Region of Spain, Denmark, Mexico, Finland and other countries maintain representation organizations in the Valley to assist their universities and firms.

Boston founded the venture capital industry, but is no longer its capitol. The concentration of venture capital is an important "pull" factor in Silicon Valley, along

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7 The student who asked the question that elicited this response could not quite believe the answer and asked in follow-up of who should do a "five year plan" and received as answer, "the US."

8 It is interesting to note that the biotech cluster has remained close to its academic source, locating adjacent to the universities like MIT and Harvard, which sparked its development. Perhaps, the decline of the Route 128 cluster may be due to its relative distance from academia and the isolated firm model that took hold.

9 In the *Social Network* film Mark Zuckerberg is persuaded to move Facebook from Cambridge Mass, to Palo Alto CA to fully realize its potential, exemplifying one direction of a two-way flow of entrepreneurs, business ideas, and technologies.

with the availability of managerial talent that combines technical and business skills, but these assets can be found elsewhere in the world too. For example, Bangalore may eventually equal or exceed the Valley, but at present the Indian software region lacks the highly developed research, if not the training capabilities, of Stanford and Berkeley. Regions, like Linkoping, Sweden (Etzkowitz and Klofsten, 2005) and San Diego, California (Casper, 2007) exhibit similar characteristics of knowledge-based development to Silicon Valley, but on a smaller scale, typically originating with the implantation of entrepreneurially oriented research universities. It took decades from their founding to achieve sustainable high-tech growth, but in retrospect, the gestation period is not overly long. Others, like Merced and Norkopping, are emulating these exemplars (Svensson, Klofsten and Etzkowitz, 2012). A focus on developing human capital may be identified as a key element in success cases, despite obstacles such as insufficient resources to cross various "Valleys of Death".

Rather than focusing on growing its own talent, Silicon Valley has become increasingly dependent upon technical talent from other countries. This growing dependence on external sources of human capital and technological innovation is a potential Achilles' Heel if competitive regions achieve "stickiness" and retain or call back these assets. Immigrant entrepreneurship now spans two generations and in contrast to previous generations of immigrants, many of these immigrants have become transnational entrepreneurs, investing in start-ups in their countries of origin and establishing offshoots of Silicon Valley firms to take advantage of low cost labour (Saxenian, 2002). Moreover, a significant number would seriously consider returning to their home countries if appropriate professional opportunities were available. Indeed these opportunities have materialised, especially as countries mount attraction programmes to incentivize return or simply call upon those they have educated to establish dual lives in both countries, once their children have grown. Taiwan has been able to staff its Innovation Agency by inviting highly successful Taiwanese "to give back" to their country of origin. Instead of investing heavily in area universities, and growing its future employees locally, Silicon Valley firms have relied on local law firms to become expert on immigration procedures. Although programmes to enhance diversity have been instituted, such as Stanford University's enrichment effort at East Palo Alto High School, to make its graduates viable applicants to leading universities, insufficient attention has been paid to the local human resource base. For example, to sustain and expand the Valley's innovation superstructure, Cogswell Polytechnic Institute should be developed into the Silicon Valley Institute of Technology, a northern California equivalent of southern California's CalTech.

Cogswell Polytechnic Institute in Sunnyvale has a similar origin to the California Institute of Technology in Pasadena, but has developed at a much slower pace. The two institutions were founded in the late 19th century as technical secondary schools. While the Throop Manual Training School rapidly transformed itself into Cal Tech in the early 20th century, with the infusion of new leadership from MIT and support from a southern California business elite, Cogswell was on a much slower track, becoming a junior college in 1930 and later a four year college. Cogswell currently has 200 students in its technology and arts tracks. Its new Chancellor, with HP and Stanford experience, may speed its development trajectory.

To sustain knowledge-based economic and social development, two fallacies must be avoided: (1) supporting research as an end in itself; and (2) building impressive buildings to house high-tech firms as a generative strategy. Instead, universities should be incentivized to become entrepreneurial or new ones founded for that purpose (Etzkowitz, 2010). Otherwise, even regions with high publication and patent ratings may remain an untapped resource and not achieve their full potential (Estrin, 2008). Decoding the DNA of knowledge-based economic development in Silicon Valley, with its largely non-descript built environment, suggests that physical structures are a lagging, not a leading element. Rather, the key to regional innovation is creation of a human capital and R&D development strategy in an institutional infrastructure characterized by permeable academic, industry and government boundaries and interacting helices.

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