INSTITUTIONS AND THE GROWTH OF SILICON VALLEY

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Abstract

The success of Silicon Valley is generally explained with reference to free-market competition or to government contracts. Proponents of these explanations overlook the critical role of informal and formal relationships among the region's engineers and executives and among its firms. This article describes the growth and evolution of Silicon Valley as an industrial district, from an early phase characterized by private networks to one characterized by more formal organizations. The existing institutional infrastructure, however, is found to be inadequate in the face of emerging threats to the region's industry. New collective institutions and public forums are required if local companies are to meet the growing challenge of international competition, if they are to secure a skilled work-force, and if they are to solve the transportation, housing, and environmental problems which affect them.

"Fathers of Silicon Valley Reunited," proclaimed *The New York Times*, referring to the eight middle-aged engineers gathered on a stage in Palo Alto, California, on April 14, 1988. The eight had founded the Fairchild Semiconductor Corporation three decades earlier. Honoring them were more than 1,000 "Fairchildren"—former employees of the company who had gathered to celebrate the sale of Fairchild to National Semiconductor, to one of its own offspring.

It might seem odd that this gathering of entrepreneurs was referred to as "fathers" and "children." Pioneers of some of the century's most significant scientific breakthroughs, they are also industrialists who won fame and considerable fortune for pioneering one of the most dynamic and innovative industrial regions in the world.

Yet it is appropriate that these eight men should be referred to as the fathers of a family. In existing stories of the origins of Silicon Valley, the region's early growth is generally attributed either to the dynamism of competitive free markets or to the propulsive role of government markets. Theorists focus either on how Stanford University, its science park, and the local supply of venture capital fostered entrepreneurship and innovation, or they stress the extensive role of the U.S. Department of Defense and NASA in promoting the early development of the semiconductor industry.

The relationships among the region's engineers, referred to here metaphorically as familial, have generally been overlooked. Yet the informal cooperation and networking between firms in Silicon Valley were as important to the region's early successes as other, more commonly identified factors. Engineers and scientists developed a commitment to one another, to the region, and to the project of advancing technology which transcended their commitments to individual firms. This culture fostered the rapid diffusion of technology, skill, and know-how within the region and encouraged a continual process of new firm formation and innovation.

Thus, the activities of local and national institutions, including Stanford University and the U.S. Department of Defense (DOD), are generally acknowledged to have contributed to Silicon Valley's early development. Equally important, but almost universally overlooked, is the way that both fostered collaboration and the rapid diffusion of market information, technology, and skill which enabled small firms to survive and constantly innovate in an uncertain and rapidly changing environment. This distinguishes Silicon Valley from most other aspiring high-tech regions—those with universities, science parks, and venture capital, on one hand, and those which receive large quantities of defense dollars, on the other.[1]

This paper suggests that Silicon Valley is best understood as an industrial district, comparable to the 19th century regions described by Alfred Marshall and to their contemporary variants being rediscovered in the technologically dynamic regions of Europe and Japan.[2] Like these European and Japanese districts, Silicon Valley's agglomeration of high-technology producers and highly skilled workers is characterized by the specialization of its producers and their ability to adapt flexibly to changing competitive conditions.

The enterprises which make up Silicon Valley's decentralized industrial structure are embedded in a social structure which supports a complex balance of cooperation and competition. While local firms compete fiercely to be first to the market with new products and processes, they simultaneously rely on dense networks of social and commercial relationships for information, technology, and contacts.[3] This decentralized, region-based pattern of industrialization distinguishes Silicon Valley from other high-technology regions in the U.S. Lacking comparable traditions of informal cooperation and networking, these regions have failed to generate the sustained growth and technological dynamism associated with Silicon Valley.[4]

The paper divides the history of Silicon Valley into three periods. It begins by reviewing the region's development during the 1950s and 1960s, highlighting the role of both Stanford and the U.S. military in creating a social and technical infrastructure which fostered innovative risk-taking and experimentation. It then describes the institutions, largely private and uncoordinated, which emerged during the 1970s to support a highly decentralized industrial structure during the region's most spectacular growth phase.

During the 1980s, Silicon Valley flourished as local firms adapted successfully to changing competitive conditions; however, the region's weaknesses also became apparent. The paper concludes by suggesting that the main constraint to Silicon Valley's continued dynamism lies in the absence of public-minded institutions to organize the responses of local firms to the shared challenges of intensifying international competition, on one hand, and the deterioration of the regional environment, on the other.

The 1950s and 1960s: Relationships Not Recipes

The experience of Silicon Valley provided the original model for the "high-tech recipe." Policy-makers worldwide assumed that by combining such ingredients as a research university, a science park, and venture capital in an environment free of government regulations or labor unions, they could "grow the next Silicon Valley."[5] The recipe, based on the assumptions of neoclassical economics, suggested that unfettered supplies of highly skilled labor, technology, and capital would automatically generate new firm formation and technology-based regional development. Silicon Valley's rapid growth, in this view, represented a triumph of free markets and entrepreneurial capitalism.

Yet the widespread failure of efforts to "grow the next Silicon Valley" suggests the limits of this interpretation.[6] The high-tech recipe overstates the role of such individual institutions as Stanford, its science park, and the venture capital industry in the development of Silicon Valley because it abstracts them from both the industrial structure and the social and economic environment of the region.

World War II laid the foundations for the industrialization of Silicon Valley, formerly an agricultural region. The hostilities in the Pacific drew large numbers of people to work in war-related industries; the Engineering Laboratory at Stanford University received substantial Pentagon funding for electronics research and development (which continued during the post-war period); and large, established electrical and electronics firms began to locate in the region to gain access to the technological watershed emerging at Stanford and to growing aerospace markets in the west.[7]

The war thus created the technological and industrial infrastructure which supported Stanford's first electronics spin-offs during the 1940s and 1950s. The contribution of Stanford's engineering dean, Frederick Terman, lay less in the formal linkages he forged between the university and local industry, as commonly assumed, than in his active support for aspiring entrepreneurs like William Hewlett and David Packard. Terman pursued his vision of a "community of technical scholars" in the region not only by building up the University's engineering department but also by supporting the entrepreneurial efforts of his students.[8] He thus initiated a culture of informal cooperation in the region which his proteges in turn replicated in their relationships with other emerging enterprises. In the words of a local analyst commemorating the fiftieth anniversary of the Hewlett-Packard Company:

> As their company grew, both [Hewlett and Packard] became very involved in the formation and growth of other companies. They encouraged entrepreneurs, went out of their way to share what they had learned and were instrumental in getting electronics companies to work together on common problems. Largely because of them, there's an unusual spirit of cooperation in the local electronics industry.[9]

One of Stanford's most significant, but overlooked, contributions to the development of Silicon Valley was thus in fostering these informal practices of inter-firm cooperation.

By the early 1960s, Silicon Valley was distinguished by a now-legendary process of high-tech entrepreneurship and industrial recombination. Between 1963 and 1972, a new firm entered the Silicon Valley electronics industry an average of every two weeks—and most were started by engineers leaving other small technology firms in the region. These entrepreneurs drew upon the assistance of colleagues and friends in the area to put new technical ideas into practice, just as Hewlett and Packard had relied on Terman's support.

This recombination process was initiated by the prodigious Fairchild Semiconductor Corporation. The majority of the semiconductor ventures started in Silicon Valley between 1960 and 1970, or close to forty ventures, trace their lineage to Fairchild Semiconductor.[10] The symbolic significance of this pattern of entrepreneurship to the region is reflected in the Fairchild family tree, a poster-sized genealogy of the firm's scores of spin-offs. This family tree hangs on many walls in Silicon Valley and underscores the quasi-familial nature of the bonds among the region's engineers.

Fairchild also served, in the words of one local executive, as a "corporate vocational school" for its employees. Many of the region's most prominent industrialists gained business and technical experience at Fairchild. At an industry conference in Sunnyvale in 1969, for example, less than two dozen of the 400 people present had never worked for Fairchild. In the early days, it seemed that "everyone knew everyone" in the region. The shared experience of working at Fairchild created a sense of loyalty and trust among Silicon Valley engineers that lasted even as individuals began to work for competing companies, a loyalty similar to those among university classmates. Thus it is not surprising that the sale of the company, long a technological has-been, drew such a huge crowd in 1988.

Socializing and information-sharing were pervasive in Silicon Valley during this early period.[11] The process of informal collaboration was essential to engineers and former colleagues who were trying to solve the enormous technical problems facing the emerging semiconductor industry. Although the region's firms competed fiercely, striving to be the first to introduce innovative new products and processes, they also cooperated. Geographic proximity facilitated open exchanges of information and the informal networking which created a sense of community among local engineers. According to one executive in the semiconductor industry:

> I have people call me quite frequently and say, "Hey, did you ever run into this one?," and you say, "Yeh, seven or eight years ago. Why don't you try this, that or the other thing?" We all get calls like that.[12]

The Stanford Science Park provided fledgling enterprises a physical environment which facilitated this mutually beneficial interaction. Yet the role of the Science Park is often exaggerated. It was important only in the broader context of a technical and social environment which fostered entrepreneurship. More than a decade of experience has demonstrated that the physical infrastructure of a science park alone does not insure mutually beneficial patterns of networking and collaboration.

By the end of the 1960s, neither Stanford University nor its science park were of real significance to the region's rapidly multiplying technology firms. Virtually all of the start-ups during the 1970s and 1980s were spun off of existing firms like Fairchild, and most had only limited relationships with Stanford or the Science Park. Rather, these firms built on the region's growing technical infrastructure and concentration of specialized skills. Stanford's importance to the region today lies primarily in its role in educating large numbers of engineers and managers.

The role of the venture capital industry in the region's development has similarly been misinterpreted. Silicon Valley's venture capital business was a product of the regional concentration of technology enterprises, not the other way around, as commonly assumed. As local entrepreneurs succeeded, some chose to invest their returns in other technology start-ups. These entrepreneurs-turned-venture-capitalists contributed not only capital to fledgling enterprises, but also their technical and managerial experience and access to networks of contacts. The venture capital industry thus grew out of and in turn helped to reproduce the patterns of informal cooperation, networking, and new firm formation in Silicon Valley.[13]

In short, the university, the science park, and the venture capital industry—the key elements of the high-tech recipe—were not simply disarticulated factors of production in Silicon Valley. This dynamic industrial region never resembled the neoclassical economic model of free-flowing resources and atomistic firms. Innovative enterprises were embedded in a broader, regional community of engineers and technology firms. The region's technical and social networks and practices of informal cooperation insured that information, technology, and capital diffused rapidly and fostered entrepreneurial initiative and innovation.

The image of Silicon Valley as a product of free markets and small firms similarly leaves out the contribution of the U.S. government to industrial fragmentation and the rapid diffusion of technical information in Silicon Valley.[14] The Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) invested close to $300 million in production contracts for semiconductors between 1955 and 1968, a large proportion of which went to Silicon Valley.[15] Yet this money is less significant for the volume of dollars spent in the region than for the way that this money reinforced a decentralized industrial structure and the social and technical relationships which supported it.

The DOD and NASA, in an effort to develop more sophisticated weapon systems rapidly, extended contracts to the region's small new ventures as well as to larger, established electronics firms. Thus, for example, the U.S. government was the largest market for new semiconductor ventures during much of the 1960s, and many of Silicon Valley's 1960s start-ups were directly supported by military contracts.[16] The presence of the military as a potential customer and a potentially lucrative market served as an ongoing inducement for local entrepreneurs to start firms and experiment with new technologies. This willingness to support untried firms contrasted with other U.S. military programs which centralized contracts and research funds in a few well-established firms.[17] The military also promoted the rapid diffusion of technology in the region through its liberal licensing and second-sourcing policies. The Defense Department required, for example, that whenever it contributed funds to the development of a product or process, a comprehensive license of free use be issued, insuring that the invention could be used by anyone in connection with government-funded projects. Scores of small subcontractors as well as prime contractors were thus able to stay abreast of the latest technological breakthroughs through this licensing policy.

Finally, the military actively encouraged the practice of "second-sourcing" parts for complex weapons systems. Using a second source was a means of hedging the risk of relying on a single subcontractor for key components which, if delayed, might slow the progress of an entire system. This served as an important means of transferring technology: second sources were typically provided not only with product specifications but also with the prized details of process technology. Moreover, second-source contracts were used by many start-ups as a means of securing the cash flow and production experience to move into innovative new products.[18]

While the importance of military spending to the Silicon Valley economy diminished significantly during the 1960s, the practices of cooperation and technology-sharing through liberal licensing, second-sourcing, and informal exchange persisted.[19] So too did the pattern of entrepreneurial spin-offs which Pentagon contracts had supported.

The unplanned coincidence of such processes contributed to the emergence of Silicon Valley as a dynamic center of technology industry in the 1960s. The region was characterized by a dense social and technical infrastructure which supported new firm formation and innovation. Other U.S. regions which have attempted to recreate this pattern of technology development, through state financing of research facilities and industrial parks, have failed to generate comparable rates of new firm formation, innovation, or growth. Lacking comparable cultures of collaboration and loyalty, the infrastructure of sophisticated suppliers, and the high rates of entrepreneurship which distinguish Silicon Valley, most high-tech regions in the U.S. are dominated by the branch plants of large, established electronics firms.[20]

Regions which have high levels of military spending have similarly failed to generate self-sustaining and diversified high-technology development.[21] Los Angeles, which may be the exception that proves the rule, has generated a dynamic high-technology base, but it remains heavily defense-dependent and lacks the innovative commercial sector which distinguishes Silicon Valley.[22] Even the Route 128 region foundered during the 1980s, in part due to its lack of a flexible industrial and social structure.

The 1970s: The Creation of a Private Institutional Infrastructure

By the 1970s, Silicon Valley was known as the world's leading center of innovation in microelectronics. It was distinguished by a highly decentralized industrial structure, with both small and large firms embedded in the relationships of a technological community. The federal government no longer played a leading role in the region. Instead, the skill-base expanded, the technical infrastructure became more complex, and a variety of institutions emerged to support this regional complex.

High levels of inter-firm mobility and entrepreneurship continued to promote new firm formation and the diffusion of technology and skill in the region. Silicon Valley was, by the mid-1970s, distinguished by the highest levels of job-hopping in the nation.[23] Average annual employee turnover was close to 60 percent in the region's small technology firms during the 1970s as it became both common and acceptable for engineers to shift frequently between firms.[24] One technical recruiter noted:

> Two or three years is about max [in a job] for the Valley because there's always something more interesting across the street. You don't see someone staying twenty years at a job here. If they've been in a small company . . . for 10 or 11 years you tend to wonder about them.[25]

This continual process of recombination strengthened the region's social and technical networks: as engineers left established companies, they took with them the skills, know-how, and experience acquired at their previous jobs, along with an expanding circle of professional and personal relationships. A technical culture developed among the members of the region's predominantly high-skilled engineering and scientific workforce, who saw themselves as different from the rest of American business. These engineers developed loyalties to the industry and the region, rather than to the individual firms where they worked.[26]

This culture accorded the highest status to those who took the risk of starting firms. More than 1,000 net new technology enterprises were established in Silicon Valley during the 1970s. While some of these establishments represented new facilities of firms from outside of the region, or the relocation of such firms, a majority were new-firm start-ups. These new ventures were virtually all started by engineers who had acquired business experience, entrepreneurial skills, and technical know-how by working in other small firms in the region. The typical start-up was formed by friends and former colleagues with an innovative idea who sought funding and advice from local venture capitalists (often former engineers and entrepreneurs themselves). And they relied on an expanding circle of local suppliers, consultants, and market researchers for additional assistance with the process of starting a new enterprise.

A wide range of specialist input suppliers, subcontractors, and service industries for semiconductor production in turn developed in the region. For example, an independent semiconductor equipment and materials industry was created as engineers left semiconductor firms and created spin-out firms to manufacture such capital goods as diffusion ovens, step and repeat cameras, testers, and the specialized materials and components for the rapidly growing chipmakers. The equipment industry was, like the semiconductor industry in the early 1970s, highly fragmented and characterized by unusually high rates of entrepreneurship and innovation among small firms.

The region's industrial structure came to be characterized by extensive vertical as well as horizontal disaggregation.[27] The expanding infrastructure of suppliers and services allowed small, specialized firms to survive in a technically uncertain and rapidly changing environment, to rely on the external economies of a dense regional agglomeration rather than pursuing vertical integration. The existence of an independent semiconductor equipment and materials industry, for example, promoted entry of new semiconductor firms by freeing individual firms from the expense of internal development and by spreading the costs of developing new capital goods across multiple producers.

The process of starting a new firm, defining a new product, or experimenting with new technologies was thus inseparable from the networks of social and commercial relationships among the region's specialized firms. While competitive rivalries were fierce, as evidenced by continually falling prices and technological advances in semiconductors, what appeared to both the actors and the outside world as an individual entrepreneurial process was in fact a social process.

The firms which emerged in this environment proved to be highly resilient. While only 75 percent of American manufacturing firms survive their first two years of business, during the 1970s and 1980s, 95 percent of the technology firms in Silicon Valley survived their first six years of business.[28]

This regional environment also fostered innovation. The decentralization of information flows, the rapid spread of market information and technology, and the availability of technical skill and expertise fostered local technical advance. While many of the major technological breakthroughs in the semiconductor industry during the 1960s and 1970s were achieved in non-Silicon Valley firms, the region's flexible enterprises excelled at exploiting technical advances rapidly and generating incremental innovations and product-engineering improvements. Silicon Valley thus became the nation's leading center of innovative, engineering-intensive forms of semiconductor production.[29]

Local venture capital networks simultaneously expanded to support this ongoing process of entrepreneurial recombination and innovation. The interplay of cooperation and competition which characterized the industrial community was replicated in the venture capital community: as individual venture capitalists rarely had the resource or expertise to evaluate the range of new technologies, they created dense networks for the exchange of information and assistance. While they often competed to fund promising start-ups, they also usually created shifting consortia to share the risk of funding companies whose management and technology were untested.

Private institutions such as trade organizations and providers of business services also emerged during the 1970s to support Silicon Valley's decentralized industrial structure. The American Electronics Association (AEA), based in Palo Alto, played a central role in the region during the 1960s and early 1970s. Explicitly focusing its activities on the Valley, it provided services as well as managerial and technical education programs to support new and emerging electronics firms in the area. The AEA's hundreds of breakfasts, lunches, seminars, dinners, and other conferences similarly provided opportunities for networking and information exchange.[30] In the words of one observer:

> Perhaps the AEA's most significant contribution to the electronics industry is what it did to foster networking. Most top executives of young, fast-growing electronics companies are relatively inexperienced in some important management areas. The AEA, with its frequent seminars and monthly meetings of company presidents, provided an excellent opportunity for those executives to meet and learn from their peers.

He goes on to point out the crucial role the AEA played in integrating the specialized firms in a highly fragmented industrial structure:

> . . . electronics companies are uniquely systems-oriented. Almost no firm manufactures from the ground up a standalone product. A company either draws on other people's components or makes products that fit with other people's products into a system. Friendships made through the AEA help the companies develop products that work together.[31]

The Semiconductor Equipment and Materials International (SEMI) similarly supported the development of the region's highly fragmented but innovative equipment manufacturing sector. SEMI was formed in 1970 in Silicon Valley to sponsor trade shows and to provide market information to semiconductor equipment and material suppliers. It soon took on the ambitious task of setting standards for the semiconductor industry. These activities allowed the hundreds of small firms which manufactured semiconductor equipment and materials to survive and innovate in an industry characterized by continual technological change.[32]

Consulting firms, market research agencies, training programs, and public relations firms—often started by engineers and former entrepreneurs—became part of the regional infrastructure as well. The market research firm Dataquest, for example, provided not only market data but also held regular conferences and gatherings which brought together the members of the industrial community to exchange information and to network. The Silicon Valley Entrepreneurs Club similarly provided a forum where aspiring entrepreneurs gathered monthly to make contacts, find partners, or learn about legal, financial, and managerial aspects of starting a new firm.

By the late 1970s, the most important institutions supporting the dynamic process of recombination and innovation in Silicon Valley were private business services and trade associations. These local institutions fostered the diffusion of technology and the continual process of information-sharing and networking among the region's hundreds of small firms. The Stanford science park and the Defense Department were no longer active in the process of new firm formation and innovation. Institutionalized forms of cooperation, such as public or private research institutes, were also virtually non-existent.

Nor did the federal government or national institutions play any significant role in Silicon Valley. Military contracts had decreased greatly as a proportion of regional output since the 1960s and had little effect on the dynamics of the commercial high-technology sector.[33] National banks and law firms located branches in the Valley but were rarely significant actors. Finally, city and county governments did little more than provide the physical infrastructure for industrial development.

As Silicon Valley entered the 1980s, the institutions which supported industrial development in the region were overwhelmingly private. Not only were the trade associations, venture capital networks, and most universities and training programs private, but so too were the consulting, market research services, and other forums for networking and technology transfer. Moreover, workers in the region's high-technology firms were not represented by unions.[34] Nor were there forums for collective oversight of this dynamic industrial region.[35]

This lack of public involvement is explained in part by the region's history. Silicon Valley's initial growth was the result of an unplanned historical process of agglomeration. Viewing their own successes as a product of individual entrepreneurial and managerial prowess rather than as the work of a regional community, local entrepreneurs and executives remained fiercely independent and shunned external intervention in their affairs. During the 1970s, they were solely preoccupied with the demands of unprecedented growth, and assumed that their dominance of world markets was unassailable. It was not until the 1980s, when foreign competition became a reality, that their individualistic world-view was challenged.

The 1980s and 1990s: The Need for Collective Institutions

Silicon Valley's technologically dynamic industrial complex continued to expand and diversify during the 1980s. However, the vulnerabilities of the regional economy also became apparent for the first time. The intensification of international competition and the accelerating pace of technological change, on one hand, and the limits of a congested transportation infrastructure and inflated housing and real estate prices, on the other, threatened to slow the region's growth. Yet there was no institutional infrastructure to address such shared problems.

There was ample evidence of Silicon Valley's continued dynamism during the 1980s. Computer systems producers and their suppliers came to dominate the regional economy, replacing the semiconductor industry as the leading sector. Innovative new firms pioneered technological advances in markets ranging from computer workstations, network hardware, and hard disk drives to microprocessors, computer-aided-design, and manufacturing software. In fact, the fastest-growing firms in the region's history, Sun Microsystems and Conner Peripherals, were formed during the decade.

Several local firms—such as Hewlett-Packard, Apple Computers, and Intel Semiconductor—became very large during this period; however, small and medium-sized firms remained prominent in the regional economy. More than 85 percent of the region's high-technology establishments employed less than 100 workers in 1985, in part the result of a dramatic acceleration in the pace of start-ups during the early 1980s.[36] Many of the region's small and medium-sized firms specialized in narrow niche markets and competed on the basis of technology, quality, and service rather than low cost.

Silicon Valley continued to expand geographically as well, with its boundaries extending beyond the traditional boundaries of Santa Clara County to encompass portions of adjacent Santa Cruz County (to the south) and Alameda County (to the northeast).

To speak of regional boundaries is not to imply that the region is a self-contained unit. Silicon Valley firms are tightly linked into the international marketplace. Most are heavily export-oriented, many rely on foreign suppliers for key inputs, and some have located production facilities overseas. At the same time, despite this global orientation, they recognize that the region's agglomeration of skill and suppliers is critical to their ongoing success.

While Silicon Valley remains the nation's leading center of innovation in semiconductors and computer systems, it no longer appears invulnerable. The crisis of the semiconductor industry highlighted this fragility. When the region's leading producers fell into crisis during the mid-1980s, many observers predicted that the region would follow Detroit and Pittsburgh into regional decline. Yet in spite of the loss of some 30,000 jobs, more than 80 new semiconductor ventures were formed in the region during the decade. By 1989, regional employment had rebounded to its pre-recession levels.[37]

Local firms adapted to the intensification of international competition by establishing organizational networks which formalized the informal cooperation of earlier decades. Producers of computer systems and components chose to focus only on the aspects of production where they could add the highest value and began to forge collaborative partnerships with specialist suppliers and subcontractors which allowed them to spread the rising costs and risks of production. In so doing, they increased their own flexibility and institutionalized the capacity for joint problem-solving and reciprocal technological advance.[38]

Despite this successful adjustment, the region remains vulnerable. Silicon Valley's decentralized networks of specialist producers depend on a collective infrastructure of social and technical networks for their flexibility and responsiveness, yet they have failed to created institutions to organize these relationships.[39]

There are several scenarios under which this uncoordinated balance of industrial decentralization and private institutions in Silicon Valley might break down and threaten the region's vitality. First, regional institutions could become increasingly exclusive, inhibiting the open diffusion of technology and skill which fosters innovative recombination. As long as local institutions remain private and beyond collective influence, there is no assurance that they will continue to promote the free exchange upon which the region depends.

The collaborative manufacturing consortium Sematech exemplifies this danger. Sematech was organized by local semiconductor firms in response to the industry's crisis and is jointly funded by the U.S. government and industry members, yet the membership requirements are such that only the largest firms in the industry can join.[40] Only 14 of the some 300 semiconductor producers in the U.S. today are members of Sematech. Cooperative research and manufacturing efforts could play a central role in sustaining the technological dynamism of Silicon Valley, but only if they include the region's highly innovative small firms as well as large producers.

Similar problems of exclusion might result from restrictions on access to venture capital or from lawsuits which undermine the trust that allows for open exchange. Such tendencies can only be avoided through the creation of public forums for explicitly considering the collective good of the region. While inter-firm mobility and technology exchange may hurt an individual firm, the process of innovative recombination benefits the region (and industry) as a whole. Such forums could create institutions to insure the availability of venture capital, foster exhanges of technical and market information, or provide services to small and medium-sized firms.

Second, decentralized regional economies remain vulnerable to a shortage of technical skill and the underprovision of research. In an environment of high inter-firm mobility, individual firms have little incentive to invest in training or research because they will not reap the benefits of their investments. These classic cases of market failure —which are intensified in a decentralized regional economy—underscore the need for collective action to ensure that local educational and training programs provide required amounts of appropriately skilled in an environment of rapid technological change.[41]

The accelerating pace of technological change also suggests the need for institutions which spread the high costs and risks of technology and product development. This might include regional research institutes which are open to all firms and pool technological expertise and support innovation in particular areas. It might also include the collective financing of a semiconductor fabrication facility which would allow start-ups which cannot afford a foundry (or which choose not to have one) to share space and avoid reliance on foreign manufacturers.

The creation of such public forums would also allow local firms to respond jointly to shared external threats. External challenges might take the form of macroeconomic shocks such as unfavorable changes in exchange rates or changes in tax laws, or they might result from unanticipated shortages of key inputs or from significant technological breakthroughs elsewhere.[42] Silicon Valley producers are not organized to respond collectively to such unexpected events. Thus they face the danger of either failing to respond or responding too slowly. Worse yet, they might respond in self-interested ways which subvert rather than strengthen the long-term foundations of the system.

The U.S.-Japan Semiconductor Trade Agreement, which established price floors on semiconductor memory devices, might be considered such an anti-region response. While trade protection temporarily benefitted the large semiconductor firms which were besieged by Japanese competition, it resulted in severe shortages of memory products and impaired the competitiveness of local systems producers. The trade accord thus appears to have served the interests of a narrow segment of firms at the expense of a broad range of other local producers.[43]

The delayed response of Silicon Valley firms to the resulting shortage of memories, itself largely a consequence of the trade agreement, underscores this problem. It took more than a year of artificially high prices and near-crisis conditions before serious discussions began among firms to devise solutions to the shortage. Discussions of creating a collective facility for manufacturing memories drew in representatives of local semiconductor and systems firms and venture capitalists; however, the long delay in developing joint solutions, as well as the apparent failure of any solutions to materialize, suggests the need for prior organization. In a world of increasing technological parity, it is essential that the region's firms have the capacity to respond rapidly to such unanticipated external threats.

Finally, such institutions would enhance the ability of local producers and policy-makers to respond to problems of the regional environment. The worsening traffic congestion, strong inflation of housing prices, and mounting environmental hazards are problems which undermine the ability of all local producers to function successfully within the region. Public forums could contribute to the process of improving the public transportation system, insuring provision of affordable housing, and monitoring workplace toxics and other environmental hazards.

In short, there is a need for collective institutions which allow for long-range thinking among Silicon Valley's specialist producers, without undermining the openness of the technological community.[44] These institutions would collaborate with existing private institutions and with local and county governments. While they might represent the region's interests to the federal government, they would be oriented locally, not towards Washington. In periods of stability, such institutions would concern themselves with developing strategies for improving the education and training system, supporting research on emerging technologies, and promoting infrastructure development. In periods of crisis, they would also be available as forums to develop collective responses to shared competitive threats.

Silicon Valley has flourished for more than four decades as a technologically innovative industrial district with virtually no conscious planning. However, the intensification of international competition has exposed the limitations of this fragile balance of industrial decentralization and private institutions. The continued responsiveness and technological dynamism of the region's specialist producers increasingly demands institutional oversight. The secret will be to create forums that allow local actors to respond jointly to shared challenges without sacrificing the individual autonomy that motivates their dynamism.

NOTES

This is a substantially revised version of "A High Technology Industrial District: Silicon Valley in the American Context," included in the conference proceedings Citta della scienza e della tecnologia, *P. Perulli, ed., Venice: Arsenale Editrice, 1989.*

[1]See the survey of 12 aspiring high-tech regions in J. Mitchell, "Silicon Valley Wannabes," *San Jose Mercury News*, August 25, 1991.

[2]On the contemporary period, see Sabel (1987), Herrigel (1988), Goodman and Bamford (1989), Imai (1989), and Friedman (1988). On the 19th century districts, see Marshall (1919), Sabel and Zeitlin (1985), and Scranton (1983).

[3]Granovetter (1985) theorizes the social embeddedness of economic activity. See also Piore (1990) on the social structures of industrial districts.

[4]Even Route 128, long considered the counterpart of Silicon Valley, does not demonstrate a comparable culture of open information exchange and networking. See Weiss and Delbeq (1987).

[5]The literature is extensive. See, for example, Miller (1985), Office of Technology Assessment (1987), Premus (1982).

[6]The experience of the 1980s clearly demonstrates that science parks are not the universal panaceas they were once seen to be. Mishall (1984), for example, concludes that well over 50 percent of science parks fail. See also Macdonald (1987). The discussion of the experience of Cambridge, England, by Saxenian (1989a) underscores the limits of the high-tech recipe. Cambridge has all of the desired attributes identified in the high-tech recipe but has failed to generate substantial or self-sustaining high-technology development.

[7]See Saxenian (1980) for a more detailed description of this process.

[8]For example, Terman helped Hewlett and Packard locate financing for their firm and he arranged for the Varian brothers' free use of Stanford's physics labs during the early years of their venture, Varian Associates.

[9]Cited in James J. Mitchell, "H-P Sets the Tone for Business in the Valley," *San Jose Mercury News*, January 9, 1989.

[10]Fairchild's first spin-off was representative of a process which continues to the present in Silicon Valley. Four of the firm's original founders—Jay Last, Eugene Kleiner, Jean Hoerni, and Sheldon Roberts—left Fairchild in frustration in 1961 to form Amelco. Of these four, only Last remained at Amelco a decade later. Kleiner left in the late 1960s and in 1972 joined another local engineer, Tom Perkins, to establish Kleiner-Perkins Associates, which is now among the most prominent and successful venture capital firms in Silicon Valley. Hoerni left in 1964 to help another ex-Fairchilder start Union Carbide Electronics. In 1967, Hoerni left with two colleagues from Union Carbide to found Intersil and subsequently went on to found several more firms.

[11]This open information exchange remains pervasive in the region today. Rogers and Larsen (1984), Delbecq and Weiss (1988), and Weiss and

Delbeq (1987) document the continued importance of networking and inter-firm mobility in Silicon Valley.

[12]Cited in Braun and Macdonald (1978).

[13]Both Bullock (1983) and Florida and Kenney (1987) conclude that the Silicon Valley venture capital industry grew out of the local concentration of technology enterprises, not vice versa.

[14]Large firms played a role in this process as well. According to industry veterans Linvill and Hogan (1977), for example, IBM was Fairchild's first customer in 1959, and soon became the largest commercial customer of the semiconductor industry.

[15]The data is from Borrus (1988). While $300 million does not seem a huge amount of money now, in the 1960s new semiconductor firms were routinely started with an investment of less than $1 million. The U.S. government spent an additional $930 million on semiconductor R&D between 1958 and 1974, much of which went to large, established firms and research universities.

[16]Tilton (1971) concludes that new firms accounted for 69 percent of semiconductor sales during 1959.

[17]Thus, while DOD programs promoted a highly fragmented industrial structure in semiconductors, in the case of the machine tool industry the Pentagon inhibited the development of spin-offs and contributed to the evolution of a militarily dependent and uncompetitive industry structure. See Stowsky (1986).

[18]For documentation of the influence of defense spending on the diffusion of technology, information, and skill, see Utterbach and Murray (1977). On liberal licensing and second-sourcing policies, see also Borrus (1988).

[19]The military share of the U.S. semiconductor market fell from 50 percent in 1960 to 35 percent in 1968 (Tilton, 1971). By 1979, the share had fallen to below 10 percent, where it remains today. Meanwhile, the emergence of the computer industry and its components suppliers, which are overwhelmingly commercial, has further reduced the region's military dependence.

[20]By the early 1980s, the Research Triangle and Austin regions recorded only 20,000 and 30,000 high-technology employees respectively, compared with close to 200,000 in Silicon Valley, according to Rogers and Larsen (1984).

[21]In an empirical study of the relationship between defense spending and high-technology development, Brown (1988) finds that high levels of defense spending are not generally associated with high levels of commercial high-technology industry. He finds Massachusetts and California unusual in the combination of high levels of defense activity and the development of high-tech industries with a commercial focus.

[22]See, for example, Markusen et al. (1990).

[23]On inter-firm mobility, see Angel (1989), Weiss and Delbecq (1987), and Delbecq and Weiss (1988).

[24]See American Electronics Association (1981). It is not uncommon for an individual to have worked for five or six different firms in twice as many years—and many have worked for twice that number.

[25]Cited in Gregory (1984), p. 216.

[26]In 1982, managerial, professional, and technical workers represented 56 percent of Silicon Valley's total high-tech workforce, three times more than the 19 percent in the average U.S. manufacturing. The professional and technical culture described here excludes the region's unskilled production workers. As Gordon and Kimball (1985) note, however, that production workers accounted for only 30 percent of the Silicon Valley workforce in 1982, compared to 70 percent in U.S. manufacturing as a whole.

[27]See Scott and Angel (1987).

[28]This is the finding of a 20-year study of 400 Silicon Valley firms between 1967 and 1987 conducted by Albert V. Bruno, University of Santa Clara School of Business. Cited in *The New York Times*, March 7, 1988.

[29]Scott and Angel (1987) document the spatial agglomeration of complex specialized and custom semiconductor production within Silicon Valley and the geographic dispersal of mature, high-volume production, such as discrete devices.

[30]The AEA implicitly recognized the regional basis of Silicon Valley's development when it chose to expand by creating a series of regional councils in other localities in order to replicate this pattern of grassroots organization. Since 1980, however, the AEA has increasingly oriented itself towards Washington D.C. and lobbying. See Saxenian (1990).

[31]From an article on the retirement of E. E. Ferrey, AEA president from 1960 to 1985. J. Mitchell, "A Valley Hero Readies to Retire," *San Jose Mercury News*, January 20, 1985.

[32]In 1986, SEMI represented over 900 U.S. members, of which 66 percent had less than 100 employees. See SEMI Membership Profile (1986). For a more extended discussion of the role of business organizations in Silicon Valley, see Saxenian (1990).

[33]A handful of firms in Silicon Valley still depend heavily on military spending, including Lockheed Space & Missiles, Westinghouse, and FMC. However, in 1985, military contracts accounted for only 15.4 percent of total shipments by Silicon Valley high-technology firms and direct employment by military contractors amounted to only 11.1 percent of the region's manufacturing workforce (Pacific Studies Center, 1987a, 1987b).

[34]Despite sporadic attempts to organize the electronics workforce in Silicon Valley, not a single high-tech firm is unionized except traditional defense contractors such as Lockheed and FMC. This reflects both the success of a progressive (if paternalistic) management culture in Silicon Valley and the limitation of the traditional organizing strategies of American unions for decentralized, high-skill industrial development.

[35]The only exception is infrastructure planning. The Santa Clara County Manufacturing Group was formed in 1978 to address the problems of the regional environment. This business organization works with local and regional governments on such infrastructural issues as transportation and housing.

[36]The increase in start-ups was largely a result of the 1978 capital gains tax reduction (from 49 percent to 28 percent), which produced a ten-fold increase in the amount of venture capital available nationwide. Almost one-

third of the total venture capital pool was invested in Silicon Valley firms during the 1980s.

[37]On the crisis of Silicon Valley's established semiconductor producers and the rise of a new wave of more flexible and specialized producers during the 1980s, see Saxenian (1989b).

[38]On the creation of inter-firm production networks in Silicon Valley, see Saxenian (1991).

[39]This contrasts with the industrial districts of Europe and Japan, where truly regional institutions, including trade associations and research institutes, provide training and market information and foster the diffusion of technology among regional networks of vertically disaggregated producers. See Herrigel (1988), Goodman and Bamford (1989), and Shapira (1991).

[40]Membership costs alone exceed $1 million, and a firm is expected to donate five engineers. These requirements make Sematech inaccessible to most of Silicon Valley's small producers. See Saxenian (1990) for more detail.

[41]The Applied Technology Institute of Microelectronics, created in 1990 at San Jose State University to provide training and applied research in microelectronics and computer technologies, is an example of such an institution. Financed jointly by local firms and by the state of California, the state community college system, and state university system, it is explicitly oriented toward meeting the training needs of the regional economy.

[42]In her case study of the Swiss watch industry, Glasmeier (1991) describes the breakdown of a regional economy due to a radical technological advance external to the system.

[43]On the adverse consequences of the semiconductor trade agreement, see Erdilek (1989) and Mowery and Rosenberg (1989).

[44]Scott and Paul (1990) describe similar institutional weaknesses in their analysis of Southern California's technopoles.

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