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Regional Networks and the Resurgence of Silicon Valley

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ABSTRACT

When Japanese competition forced the US semiconductor industry into crisis in the mid-1980s, observers predicted the demise of Silicon Valley. Yet the region's economy is flourishing in the late 1980s because a wave of new semiconductor start-ups is pioneering a flexible model of production in the region. By building on the dense networks of social and professional relationships which were created and then abandoned by the established semiconductor firms, these enterprises are creating a new Silicon Valley--one which fosters reciprocal innovation among networks of specialist producers. Despite this resilience, the regional economy remains vulnerable, suggesting the need for institutions and policy to support such regional flexible production systems.

During the 1970s, the rapid growth, technological vitality, and entrepreneurial culture of Silicon Valley captured the imagination of policymakers and scholars around the world. This enchantment waned during the 1980s, however, as intensified Japanese competition left the region's leading semiconductor producers saddled with massive overcapacity and declining profits. Between 1984 and 1986, local chipmakers' sales plunged 35 percent, forcing them to lay-off more than 7,000 employees while linked sectors eliminated another 20,000 jobs in the region.[1] Observers--drawing parallels with Detroit and Pittsburgh--were quick to predict the demise of Silicon Valley.

Despite this battering, more than 80 new semiconductor firms have been started in Silicon Valley during the past decade. This wave of new chipmakers represents the state-of-the art in semiconductor design and product innovation and has generated some 25,000 jobs and more than $2 billion in annual sales.[2] While the region's established producers struggle to stay in the black, several of these start-ups boast growth rates of 45-50 percent a year and only a handful have failed. Firms in linked sectors--from computer systems and software to disk drives and other peripherals--are flourishing as well.

The dynamics of Silicon Valley's revitalization are reflected in the new wave of semiconductor start-ups. These firms, together with hundreds of neighboring technology firms, are forging a flexible new model of production in the region. By building on the dense networks of social and professional relations which were created and then abandoned by the established semiconductor firms, these small- and medium-sized enterprises are pioneering a new Silicon Valley--one which fosters collaborative manufacturing and reciprocal innovation among networks of specialist producers.

REINTERPRETING SILICON VALLEY

The experience of Silicon Valley suggests that the current debate over the future of America's high-technology industry is miscast. Although public attention is currently focused on trade policy, Sematech, and high-definition television, the resilience of the Silicon Valley economy underscores the importance of regional economies to industrial competitiveness and the need for explicitly regional institutions and policy in the 1990s.

Both advocates of national support for strategic industries, such as MIT's Charles Ferguson, and their free market adversaries, led by George Gilder, attribute the early growth of the American semiconductor industry to the individual entrepreneurs and small enterprises of Silicon Valley. They disagree only on the viability of such market-led growth in the 1980s--with the latter glorifying it and the former viewing it as inappropriate, even "pathological."[3]

For free marketeers such as Gilder, Silicon Valley's dynamism confirms the neoclassical vision of competitive markets as efficient and self-reproducing. These observers see entrepreneurship as the solution to America's industrial woes. Yet they conveniently ignore the role of military procurement in supporting the region's early entrepreneurs, and they cannot account for the current weakness of U.S. semiconductor firms relative to the giant government-supported Japanese producers. Nor can they explain the failure of regions around the world to replicate the Silicon Valley experience, even after insuring unfettered flows of capital, skilled labor, and technology.[4]

National policy advocates such as Ferguson, by contrast, invoke the crisis of the semiconductor industry to argue that Silicon Valley's small- and medium-sized enterprises are no longer appropriate to the dictates of global competition. Claiming that the fragmented structures of competitive capitalism are no match for the institutionalized coordination of America's industrial adversaries (such as Japan and Korea), these analysts advocate government support and consolidation of key technology sectors. Yet the resurgence of the Silicon Valley economy--particularly the flourishing of the 1980s start-ups--casts doubt on this approach as well.

Despite their differences, these opposing approaches regard individual firms and national governments as the only relevant units of analysis. As a result, neither can account for the striking resilience of the Silicon Valley economy: it is neither a market- nor a state-led phenomenon. A more fruitful approach begins with the region itself and the relationship between its productive organization and social and institutional environment.

A growing literature compares Silicon Valley to the technologically dynamic industrial districts of Europe, where innovative producers successfully export a shifting combination of high-value-added products to global markets.[5] These regions are distinguished by industrial decentralization and vertical and horizontal linkages among specialist producers of all sizes. In these districts, external economies replace internal economies of scale, cooperation complements competition, and the region replaces the firm as the locus of production; the result is a networked system which is more flexible than the traditional vertically integrated corporation.

By focusing on the organization of the regional economy, these analysts are better able to explain the development of Silicon Valley, yet they cannot account for the crisis of the large semiconductor producers any better than the free marketeers. Much of this literature implies that productive decentralization and spatial proximity alone will generate a virtuous cycle of regional advance.[6]

The experience of Silicon Valley during the 1980s demonstrates, by contrast, that industrial districts are not self-reproducing. It suggests instead that they can be quite vulnerable, and provides insights into the social and institutional conditions needed to sustain such decentralized productive systems.[7] In particular, it highlights the importance of inter-firm cooperation and the need for regional institutions to coordinate the activities of firms in these flexible systems.

The first section of this paper argues that Silicon Valley's new wave of semiconductor start-ups is creating a flexible model of production which is the inverse of the mass production model of the region's established chip-makers. Section two describes how these specialist producers are rejecting the autarchic approach which led their predecessors into crisis, and formalizing collaborative relationships with customers and suppliers. The third section argues that computer systems firms, which now dominate the Silicon Valley economy, are also collaborating with suppliers to create inter-industry production networks.[8] These network relationships are as important as the individual firms to sustaining the technological dynamism of the region.

Yet Silicon Valley remains vulnerable. The new wave of start-ups is better adapted to respond to today's volatile markets and technologies than their predecessors, yet they too have failed to recognize the collective sources of their own dynamism. The conclusion suggests a need for regional institutions which insure the technological position and coordinate the activities of the firms in this decentralized productive system.

THE NEW WAVE OF SEMICONDUCTOR START-UPS

The wave of semiconductor start-ups in the 1980s represented a collective revolt by Silicon Valley engineers against the established semiconductor firms.[9] Successful entrepreneurs like Cypress Semiconductors' T. J. Rogers and Chips and Technologies' Gordon Campbell quit jobs at the large semiconductor firms in frustration with their employers' growing isolation from customers and unwillingness to pursue promising technical leads. Complaining that the big firms had lost the agility which made Silicon Valley famous, these engineers "voted with their feet" and exposed the rigidities of the established semiconductor firms even before Japan did so.[10] They also created the largest wave of new start-ups in the industry's history (see Table 1).

These start-ups have pioneered a flexible approach to semiconductor production--one which appears well adapted to the market conditions of the 1980s. By unbundling production, these new firms have spread the costs and risks of developing state-of- the-art semiconductors, and by adopting flexible design and manufacturing technologies they have remained highly focused and responsive while avoiding the price wars which accompany commodity production.

While established firms like Advanced Micro Devices (AMD) and National Semiconductor (NS) mass-produced general-purpose semiconductors such as commodity memories and microprocessors, the newcomers specialize in short runs of high-value-added components, including semi-custom and custom chips as well as standard parts targeted at niche markets. Cypress Semiconductor, for example, manufactures more than 75 specialized, high-performance products on a single flexible manufacturing line. While few of these individual application niches are large or stable enough to attract a major competitor, they collectively represent a $1.4 billion market--comparable to the market for 256K DRAMS. Specialist producers like Cypress emphasize product design, quality, and high levels of customer service, not simply low cost.

The new firms have achieved flexibility in manufacturing by avoiding the dedicated high-volume production lines of their predecessors. In a move reminiscent of the mini-mills of the U.S. steel industry, they have pioneered the use of "mini-fabs" which process short runs (small wafer lots) of many different designs quickly and with high yields. And while the traditional "mega fab"--optimized for very high throughput of a single design--costs $250 million and takes 2-3 years to build, a "mini fab" can be built in six months for only $20-50 million.[11]

Developments in electronic design automation--which combine advances in computer aided design (CAD), engineering (CAE), and testing--enable these start-ups to be still more responsive. Chip and systems designers are increasingly able to implement their ideas directly onto silicon; and it now takes weeks rather than months to design custom and semi-custom integrated circuits, while complex niche products at the very-large-scale-integration (VLSI) level are being developed in months rather than years.

Finally, by unbundling the production process these start-ups have spread the prohibitive costs of chipmaking. While the established firms designed, manufactured, and assembled integrated circuits in-house (and occasionally even ventured into systems production), the new firms tend to be highly focused. Many, such as Weitek and Altera, specialize exclusively in chip design and subcontract manufacturing, while others, including Cypress and Integrated Device Technology (IDT), specialize in leading-edge process technologies. Application-specific integrated circuit (ASIC) producers LSI Logic and VLSI Technology provide software and assistance to systems firms designing semicustom chips which they then manufacture, while still others, like Orbit Semiconductor, serve solely as quick-turnaround, high-performance manufacturing foundries for chip and system houses.

Unbundling allows each of these highly focused firms to remain at the leading edge of their particular technical expertise. It also dramatically reduces the investment required to produce state-of-the-art semiconductors: Sun Microsystems, for example, developed its Sparc microprocessor for less than $25 million.[12] The continued success of small firms such as Cypress, IDT, Altera, and Chips and Technologies demonstrates that neither scale nor vertical integration are necessary to survive in the increasingly capital-intensive semiconductor industry. By focusing and relying on networks of specialized suppliers, Silicon Valley's small firms introduce state-of-the-art products faster than their more integrated competitors.[13]

As they continue to introduce differentiated new products, these specialist producers are fragmenting mass markets for semiconductors--forcing the established producers to become more flexible. In the words of John Rizzo, Weitek's Vice President of Marketing:

> You've got to keep subdividing the market and making the niches smaller and smaller. A $1.5 billion market is not one product, it's one hundred products.

And as fast-growing demand for semi-custom products such as gate arrays turns them into commodities, ASIC firms like LSI Logic are moving further up-market, designing higher-performance products for narrower, more specialized niches. Even the prototypical commodity market, standard memories, is now being segmented by a proliferation of specialized products more tightly coupled to particular applications or systems.[14]

In short, while the region's established producers sought to be low-cost producers of general-purpose commodity devices, the new Silicon Valley firms are competing by getting to market first with a continuing flow of innovative products targeted at highly specialized needs.[15] They rely on flexibility, service, and variety rather than on achieving high volumes to move down the "learning curve" and reduce unit costs.

THE IMPORTANCE OF REGIONAL NETWORKS

These specialization strategies allowed firms like Cypress and LSI Logic to grow profitably even during the semiconductor industry's worst downturn in 1985-86. But the success of these start-ups is not simply the work of individual entrepreneurs, nor is the region's continued vitality a demonstration of the intrinsic dynamism of free markets. These new firms have built on Silicon Valley's dense networks of social and professional relationships, and their successes--like those of their predecessors--are inseparable from an environment rich in skill and know-how where engineers are often more loyal to the industry and to advancing technology than to any individual firm.

The region's established producers created this culture during the 1950s and 1960s; but they abandoned it in the 1970s as they shifted to high-volume production. Viewing regional traditions of informal collaboration and networking as attributes of immaturity rather than sources of dynamism, they standardized products and processes and distanced themselves from customers and suppliers. The 1980s start-ups, by contrast, are not simply building on but also formalizing their relationships with customers and suppliers both within and outside of the region.

Building on Informal Networks

When Wilf Corrigan left Fairchild Semiconductor in 1979, he sounded out former customers and colleagues on the potential market for semicustom integrated circuits. He encountered a former employee, Robert Walker, who had recently completed research for an article on the custom chip business. Walker joined Corrigan to write a business plan for a firm called LSI Logic Corporation, and they secured financing from a handful of Silicon Valley's leading venture capital firms, including former colleagues at Kleiner Perkins.

The two then recruited a team of engineers Walker had worked with on CAD and custom chips at Fairchild during the 1960s. This reunited group referred to themselves as the "over-the-hill gang," reflecting the distinctive loyalty and solidarity among the region's engineers. The start-up in turn gained technical support from local trade associations, market research firms, and public relations specialists. By 1985, when LSI Logic went public (in one of the largest initial public offerings in the industry's history), it had created a burgeoning market for ASICs.[16]

Similar entrepreneurial histories are commonplace in Silicon Valley, where the region's networks and institutions foster the continual recombination of skill and technology into new enterprises. More than 100 new technology firms were started in 1988 alone; and most of these new enterprises succeeded. A recent study found that while only 75 percent of U.S. manufacturing start-ups survive their first two years, 90 percent of Silicon Valley start-ups survive their first six.[17]

It is not simply the concentration of skilled labor and suppliers and the externalities they generate that distinguish the region (as many economic accounts would have it.)[18] Equally important to Silicon Valley's dynamism are the dense networks of social relationships and the trust that develop with shared professional experiences, repeated interaction, and geographic proximity. A variety of regional institutions--from business organizations, trade associations, and universities to public relations, consulting, market research, and venture capital firms--provide services to the region's small- and medium-sized firms. They also promote the informal cooperation, the continual interaction, and the pervasive information-sharing which allow local firms to respond rapidly to emerging technologies and market opportunities.

And while legendary rates of inter-firm mobility may mean losses for individual firms, intangible skills and know-how which can be gained only through experience with particular machines and processes spreads primarily through the movement of people or hands-on learning. This tacit knowledge is key to innovation, particularly in the complex process of semiconductor production.[19] The region as a whole thus benefits from an ongoing process of experimentation and adaptation, as new ideas are recombined with existing skills and know-how.[20]

"Outgrowing" the Networks

The value of these relationships is demonstrated by the competitive difficulties of the region's established semiconductor producers--the "fathers" of Silicon Valley--as they abandoned the networks. The companies which had made Silicon Valley famous for their responsiveness and innovation abandoned specialty production during the 1970s.[21] Faced with the growing threat of low-cost Japanese producers, they invested heavily in dedicated, high-volume fab lines and facilities in order to reduce unit costs.[22] Not surprisingly, they quickly grew from the small, flexible enterprises which had made Silicon Valley famous into large, commodity-oriented corporations. Most predicted an end to entrepreneurial start-ups in the semiconductor industry.[23]

Rather than recognizing the importance to the region of their responsiveness and ability to continually innovate, the merchant semiconductor firms chose an autarchic approach to mass production. As they standardized products and processes to achieve high-volume output, they saw little need for the interactive relationships with customers which had characterized specialty production.

Intel co-founder and industry leader Andrew Grove announced in 1979, for example, that the task for the Eighties was to "market pre-fabricated mass produced solutions to users."[24] The customer thus soon became, in the words of another executive, "a distant entity" to the merchant semiconductor producers.[25] As a result, firms like NS, AMD, and Intel missed a series of key technical and market opportunities, including the development of the CMOS process and the emergence of markets for ASICs and chip sets.

Not only did the large chipmakers distance themselves from their customers, but they also antagonized their equipment suppliers--which tended to be small, undercapitalized firms.[26] As they geared up for volume production, the merchants sought to shift the burden of increasingly severe business cycles onto their suppliers by double-ordering during boom times and cancelling orders abruptly during downturns. Forced to minimize costs, they distanced themselves from key vendors, playing them off against one another for price reductions. This reinforced the tendency of the financially weak equipment-makers to ship products which were not fully debugged, contributed to the growing climate of distrust, and eliminated any possibility of jointly refining the sophisticated and complex process of manufacturing semiconductors. The inferior quality and lower yields of U.S. semiconductor manufacturers relative to their Japanese competitors was the direct result of this arms-length relationship.

Even the informal cooperative practices of the 1960s and 1970s--including cross-licensing and second-sourcing--were largely abandoned. Conveniently ignoring their own genesis, the merchants initiated lawsuits against former cross-licensees, and suspected imitators and employees who left to start their own firms.

Finally, driven by the pressures of commodity production to minimize costs, Silicon Valley's merchants shifted manufacturing out of the region to lower-cost locations, both in the U.S. and overseas. While semiconductor assembly and test operations were shifted to Asia during the 1960s to exploit substantial wage differentials, during the late 1970s the merchant producers began to relocate wafer fabrication facilities to lower-cost areas within the U.S..[27] Only high-level research, design, and prototype production remained in the high-cost Silicon Valley. This spatial separation of design, manufacturing, and assembly further undermined the ability of local semiconductor firms to improve products or to respond rapidly to market changes.[28]

By pursuing this autarchic version of mass production, Silicon Valley's leading chipmakers abandoned the flexibility and dynamism which had distinguished them in the past.[29] In the words of one Intel vice president:

> Remember what Silicon Valley companies were good at to begin with: sensing new market opportunities, new market development, and prototype product development . . . . Until recently, the GNP of Silicon Valley was all new products. Silicon Valley simply hasn't been well positioned to handle the commodity market.[30]

This is not to suggest that the shift to mass production was a mistake. Silicon Valley's producers could have pursued a successful mass-production strategy without abandoning their customers and suppliers: this would have looked far more like the Japanese model, where learning from customers and suppliers is built into the industry structure and where product development, manufacturing, and assembly remained spatially proximate.[31] By adopting an autarchic version of mass production just as the Japanese were refining a more highly integrated approach, however, Silicon Valley's established merchant producers lagged in manufacturing improvements and product quality, and quickly lost market share to Japanese competition.

Formalizing the Networks

Silicon Valley's 1980s start-ups, by contrast, are not simply building on the region's social networks, they are formalizing them. Rejecting the arms-length relations of the commodity producers, these newcomers are forging partnerships with customers and suppliers in order to monitor changing markets and jointly redefine products and manufacturing processes. Some of the most successful firms have maintained manufacturing as well as design and development activities within Silicon Valley.

The proliferation of strategic alliances is one indication of this reorientation. The new start-ups have forged more than 350 alliances since 1979, mostly focused in semi-custom and specialty production and involving either the subcontracting of advanced fab facilities or technology-sharing and joint product development.[32] Some involve collaboration with other local start-ups, such as the alliance between Cypress and Altera to jointly develop electronically-programmable logic devices; while others involve established firms, as in the technology licensing and manufacturing agreement between Seeq Technology and National Semiconductor for high-density Flash EEPROMS.[33]

Engineers characterize these relationships as partnerships distinguished by a mutual commitment not to abandon each other during downturns or exploit advantages during upturns. With time, the best evolve into highly interactive, trust-based relationships involving technology-sharing and joint product design and problem-solving. Vice president Jeffrey Miller at Silicon Valley start-up Adaptec reports, for example, that:

> We have a closer relationship with our fab at International Microelectronic Products than I had with the in-house foundry when I worked at Intel.[34]

Such collaboration is not limited to small firms. Hewlett-Packard, for example, has opened up its state-of-the-art foundry for design specialist Weitek to manufacture a high-speed data-crunching chip. As a result, H-P now differentiates its workstations with a faster chip than it could have bought or designed in-house, while Weitek sells this more sophisticated chip to other systems makers. Both see the relationship as the basis for future collaboration.

Explicitly rejecting the distrustful, arms-length relations between the merchant chipmakers and their equipment vendors, engineers at LSI Logic, Seeq, and Cypress underscore the importance of continuous interaction with their equipment suppliers to refine complex manufacturing processes.[35] They are, for example, collaborating with suppliers of equipment such as wafer steppers and automated test equipment to design and debug products which allow for rapid product change and reduced equipment set-up times.[36]

The new chipmakers are building partnerships with customers as well, in order to accommodate the accelerating pace of new product introductions. ASIC producers like LSI Logic and VLSI Technology interact continuously with systems firms and other customers in order to assist them in designing chips for highly specialized applications. Not surprisingly, this involves extensive sharing of proprietary information, and LSI engineers report developing very close relationships with their customer's engineers.[37]

Specialist firms such as Cypress and IDT similarly treat customers as an extension of their organizations. These firms need a detailed understanding of systems trends in order to define and design products for a highly focused niche of narrow markets. Larry Jordan, IDT's marketing director, reports that the firm has chosen to ally itself closely with approximately ten, fast-growing, small- to medium-sized systems firms which it sees as future trendsetters. By building close, trust-based relationships with companies like Sun Microsystems and Silicon Graphics that are introducing new technologies and architectures, IDT keeps apprised of the details of fast-changing systems requirements and market trends.

Design specialist Weitek is so committed to building close ties with customers that it maintains one applications engineer for every field salesman--compared with an engineer for every 16 salesmen at a traditional firm. Weitek's marketing VP Rizzo tries to:

> . . . create an intangible bond and loyalty between ourselves and the customer. Those intangible bonds are the hardest thing for a competitor to break.

Of course all of these relationships are not within the region--or even within the U.S. Hundreds of alliances have been formed between domestic and foreign technology firms. One of Weitek's closest relationships is with Texas-based Compaq; Chips and Technologies relies heavily on foundries in Japan as well as Silicon Valley; and H-P is jointly developing its RISC microprocessor with Hitachi.[38] The remarkable fact, however, is that competitive pressures for rapid and frequent new product introductions place a growing premium on collaborative supplier relations--which confers an advantage to local suppliers of critical inputs (or non-local suppliers with a local facility). Thus new and established semiconductor firms alike continue to locate in Silicon Valley, in spite of exorbitant housing prices and high labor costs.

THE CREATION OF REGIONAL PRODUCTION NETWORKS

This search for flexibility and focus is not limited to Silicon Valley's chipmakers. During the past decade, the region has seen hundreds of new start-ups in sectors ranging from disk drives to electronic design automation, from networking software to test equipment. In fact, systems firms, not semiconductor manufacturers, are now at the center of the emerging production networks in Silicon Valley. Start-ups like Silicon Graphics, Pyramid Technology, Mips Computers, and Sun Microsystems are using ASICs and new generations of specialty chips to fragment systems markets with 3-D graphics supercomputers, super-mini computers, high-performance engineering workstations, and the like.[39]

By building long-term collaborative relations with specialized contract manufacturers and suppliers of software, microprocessors, disk drives, and network hardware, Silicon Valley systems firms are spreading the costs and risks of new product design and production, dramatically reducing their time to market, and increasing the frequency of new product introductions. Sun Microsystems, for example, introduced four major product generations in its first five years of business. This in turn has forced the region's large systems producers such as Apple and Hewlett-Packard to become more flexible.

Sun is representative of this new wave of systems firms: Sun does only product design, software, prototyping, and final assembly in-house, subcontracting the rest of its inputs--from microprocessors to disk drives to terminals--from the rich infrastructure of suppliers in the valley and elsewhere. Not only does this spread costs, but it allows the firm to innovate jointly with its suppliers. And when Sun involves its contract manufacturer Solectron in the process of designing, as well as producing, the central processing units and peripherals for its workstations, or when a team of Sun and Cypress engineers collaborate in a shared facility to develop a high-performance version of Sun's Sparc microprocessor, the boundaries of these firms begin to blur.

Despite this blurring, however, both customers and suppliers make an explicit effort to preserve each other's autonomy. Most companies prefer that no customer, itself included, account for more than 20 percent of a supplier's output, and many take steps to ensure that their suppliers survive hard times.

When several of Adaptec's major customers went out of business simultaneously, for example, a key supplier extended credit to the firm, enabling it to stay in business. Other firms have gone out of their way to identify and develop new customers to help their suppliers through tough periods or to help them diversify their markets. The relations between customers and suppliers are thus increasingly those of equals--horizontal rather than vertical relationships.

Apple purchasing director Jim Bilodeau claims that good partnerships with key vendors involve not simply on-time delivery and quality control but continual extension of the relationship to new areas. He suggests that joint investment in new capital equipment, joint product development, and technology exchanges, or shared funding of key engineering talent, are all ways to:

> build suppliers that you can keep healthy and they in turn will keep you healthy . . . The more you can get your vendors to think about you when building new products the better.

In short, the process of solving technical problems and charting future directions in a technologically volatile environment is increasingly a collaborative effort by a network of closely linked firms.

As collaboration extends to a wider circle of firms, it generates a process of complementary innovation between these autonomous but interdependent producers. Suppliers spread the experience and know-how gained from serving a customer in one sector to customers in other industries. This preserves the technological vitality of the region and insures that, in the words of Sun's purchasing director Jim Metcalf, "the world's best suppliers are in Silicon Valley."

This process of reciprocal technological upgrading is clear in the transformation of the local contract manufacturing industry. Flextronics, one of the region's largest contract manufacturers, has grown explosively during the

1980s as it shifted from being a consignment assembler (the classic job shop) to a full turnkey assembler with responsibility for selecting suppliers as well as assembling and testing printed circuit boards.[40] The business is changing from low-skill, low-tech assembly into high-skill, capital-intensive manufacturing--particularly as firms like Flextronics and Solectron invest in such sophisticated new technologies as surface-mount technology. By focusing and serving a range of customers in different businesses, they have achieved a level of manufacturing expertise which surpasses that of most of the region's systems firms.

Collaborative manufacturing is by no means limited to Silicon Valley firms, yet there is little doubt that geographic proximity fosters the frequent interaction and personal trust needed to maintain these relationships.[41] Robert Todd, CEO of Flextronics, claims that, in his business, close and collaborative relationships cannot survive over great distances for long. As a result, Flextronics has built regional centers around the U.S. to serve localized clusters of customers. As Apple's Bilodeau notes:

> Our purchasing strategy is that our vendor base is close to where we're doing business. We like them to be next door. If they can't, they need to be able to project an image like they are next door.[42]

The need for continual interaction and for access to the region's accumulation of skills and know-how--particularly in a period of market volatility and rapid new-product introduction--thus motivates firms to continue clustering in Silicon Valley.

CONCLUSION

Silicon Valley's networks promote innovation because they foster collective problem-solving among specialist firms and the continual recombination of skill and technical resources. Local firms are organizing themselves to learn with their customers, suppliers, and competitors about what to make next and how to make it.[43] The informal networks which promoted the diffusion of skill and technology in the region in the 1960s and 1970s are being formalized in the 1980s.

As a result, Silicon Valley is flourishing in the late 1980s, despite the ongoing crisis of the commodity chipmakers.[44] Local firms generated more new jobs between 1980 and 1986 than those in other leading high-tech centers such as Boston's Route 128, Southern California's Orange County, and North Carolina's Research Triangle.[45] And as the region continues to spawn new firms and technological advances, its geographic boundaries continue to expand beyond Santa Clara County. High-tech activity has now spilled north into San Mateo County, east to Alameda County, and south to Santa Cruz.

Nevertheless the region remains vulnerable. Local firms continue to externalize their activities and the boundaries between firms continue to blur, yet there is no mechanism for regulating this decentralized productive system. The coordinating functions accomplished by corporate hierarchies in the vertically integrated firm are achieved only through an unstructured system of collaborative supplier relationships and informal social networks and associations.

The competitive difficulties of the semiconductor equipment industry are indicative of the need for institutions to assist local firms responding to the immense uncertainty and rapid pace of technical change in the industry. These institutions could provide long-term research, training, and management education, export assistance, and other services which the region's entrepreneurial and often undercapitalized firms typically cannot provide themselves. Once established, they would provide a forum to coordinate responses collectively to external threats such as technological advances from outside of the region.

Such institutions can only be created through public action. Not only must engineers and managers in Silicon Valley overcome their deep-seated distrust of the public sector, but they must also recognize and articulate the social basis of their successes. So long as engineers believe that the region's dynamism is a product of inspired individual entrepreneurs, they will overlook the importance of the region and its relationships. The real challenge facing Silicon Valley entrepreneurs is to transcend the individualistic categories of American social science and business in order to recognize the need for public forums to both build a consensus and establish explicitly regional institutions which cut across individual firms and sectors.

The distrust generated by the semiconductor trade agreement underscores the need for regional institutions. Silicon Valley's established semiconductor producers responded to the escalation of Japanese competition by mobilizing the Semiconductor Industry Association (SIA) in the late 1970s. In 1986, after intensive lobbying, they achieved a trade agreement with Japanese producers. Yet this victory came at the expense of alienating the region's systems firms (and their customers), because it raised the price of memory chips and ultimately contributed to a destructive shortage of computer memory.

The subsequent success of the SIA in gaining government funding for Sematech has further isolated the merchants from the rest of the semiconductor industry. Sematech has been billed as a collaborative manufacturing consortium for the U.S. semiconductor industry, yet none of Silicon Valley's recent start-ups have joined because its fees are prohibitive to all but the largest firms.[46] In fact, only 30 of the more than 200 semiconductor firms in the U.S. are members of Sematech. While public support for cooperative research and development or manufacturing could play a key role in preserving the technological position of the U.S. semiconductor industry, a policy which excludes a majority of the industry's most innovative producers from the outset is unlikely to do so.[47]

The infrastructure for more effective regional institutions already exists. The American Electronics Association (AEA)--which until the late 1970s was primarily a regional organization supporting the development of small firms in Silicon Valley--remains one of the most important focal points for information exchange among local producers.[48] As the only cross-cutting industry association in the region today, it is well positioned to serve the shared interests of firms in electronics-related industries by providing the collective services that most cannot support on their own. This would involve expanding services the AEA already provides, such as training and management education, and initiating others, such as long-term research and development and technical support.

A more inclusionary Sematech and an AEA with a broader mandate would be only a start. They in turn would need to encourage the definition and creation of a far richer range of institutions in Silicon Valley, institutions which could coordinate cooperation among the region's firms, insure the continued diffusion of technology and skill, and preserve the flexibility and technological dynamism of its networks of specialist producers. But first the public debate must begin.

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ENDNOTES

[1]"The chips are down," San Jose Mercury News, Dec. 1, 1986.

[2]Dataquest Survey of Semiconductor Start-ups (1988) and "Largest 25 Semiconductor Companies in Santa Clara County," The San Jose Business Journal, February 13, 1989.

[3]Ferguson (1988), Gilder (1988, 1989).

[4]See Saxenian (1989b) for discussion of the failure of this "high-tech recipe."

[5]These regions are modern counterparts of the 19th century industrial districts described by Alfred Marshall. See Goodman et al. (1989), Storper (1989), Storper and Scott (1988), Scott (1988), Sabel and Zeitlin (1985), Piore and Sabel (1984).

[6]See, for example, Scott (1988) and Scott and Angel (1987).

[7]This approach builds on the theoretical lead of such scholars as Sabel (1988), Granovetter (1985), and Herrigel (1988).

[8]A growing literature describes network forms of organization, yet there is little discussion of the conditions needed to establish and maintain these forms. Scholars stress vertical disaggregation and the redefinition of supplier relations between complementary producers in this hybrid model, which falls between Williamson's ideal types of market exchange and bureaucratically administered hierarchy; and all agree that such networks provide the flexibility and responsiveness which are critical to the new competitive environment. See Miles and Snow (1987); Johnston and Lawrence (1988); Powell (1987); Johanson and Mattson (1987).

The case of Silicon Valley suggests that geographic proximity fosters the trust and reciprocity which are crucial to the sustained viability of production networks.

[9]The research for this project was based on more than fifty open-ended interviews with Silicon Valley executives, managers, engineers, and venture capitalists conducted between 1986 and 1988. Complete listing of the interviewees and a more complete discussion of the methodology and findings of this research appear in Saxenian (1989c).

[10]See, for example, Rogers (1988) and Rice (1987).

[11]The start-ups typically produce 100-200 different types of chips on the same line, with production runs of between 10 and 10,000 units. The established U.S. producers, by contrast, produce 10-20 different commodity memory or logic devices on a line, with runs exceeding a millions units. M. Mehler, "Mini-fabs Reshape IC Production," Electronics Business, June 1, 1987, and Borrus (1988).

[12]"Computer Maker Aims to Transform Industry and Become a Giant," Wall Street Journal, March 18, 1988.

[13]In fact, Cypress has chosen to support spin-offs as independent start-ups rather than attempting to grow internally and lose focus. The firm provided \$7.4 million to fund start-up Aspen Semiconductor and \$1 million to Multichip Technology Corp, both of which are located in Silicon Valley.

[14]B. Cole, "By the Mid-90's the Memory Market Will Look Like the Logic Business," Electronics, August 1988.

[15]B. Cole, "Getting to the Market on Time," Electronics, April 1989.

[16]Analysts predict that, by 1992, ASIC devices will account for 24 percent of integrated circuit sales (Cole, 1989).

[17]These are the results of a study of more than 400 Silicon Valley companies over a 20-year period (1967-1987) conducted by Professor Albert V. Bruno, University of Santa Clara School of Business, cited in The New York Times, March 7, 1988.

[18]See, for example, David and Rosenbloom (1987).

[19]For recent economic literature on the importance of tacit knowledge to innovation, see Dosi (1989) and Nelson and Winter (1982).

[20]Many Silicon Valley firms recognize the benefits of this process, and actively support it. Amdahl Computers, for example, supported the formation of Saratoga Semiconductor in 1985 by a team of eight of its engineers: Amdahl offered the new firm advice on financial planning, arranged venture capital financing for it, and gave Saratoga first options on its used equipment. Apple is also well known for its support of spin-outs in linked sectors.

[21]The flexibility of Silicon Valley semiconductor firms in the 1960s and 1970s came primarily from their small size and lack of automation. These firms avoided automation because the rapid pace of change in products and processes meant that investments in automation would be obsolete before costs were recovered. This contrasts with the flexibility of the 1980s start-ups, which lies in the adoption of flexible design and manufacturing technology.

The early history of the industry reflected a recurrent tension between strategies of product specialization to serve particular applications and standardization to achieve scale economies. As late as the early 1970s, the general consensus of the industry was that the future lay in customization of large-scale integrated circuits, and that the role of standard products would be small. The history is detailed in Wilson et al. (1980).

[22]Between 1978 and 1980 alone, domestic semiconductor manufacturing capacity doubled and capital expenditures increased from eight to twenty percent of sales. In 1980, the top seven merchants spent over $1 billion on plant and equipment--which represented a 51 percent increase over 1979, which in turn was 63 percent higher than in 1978. Business Week, July 21, 1980.

[23]A. Robinson, "Giant Corporations From Tiny Chips Grow," Science, Vol. 208, 1980.

[24]Cited in The San Jose Mercury News, May 4, 1980.

[25]H. Jarrat, "A Look at the Semiconductor Industry in the 1990s." Speech presented to Robertson, Coleman, and Stephens at The 1990 Semiconductor Conference, September 23, 1987.

[26]This section draws on Stowsky's (1988) insightful analysis of the semiconductor equipment industry.

[27]See Saxenian (1980) and Scott and Angel (1987) for documentation of this process.

[28]See, for example, Markides and Berg (1988)

[29]This is ironic since, during the 1970s, the U.S. auto industry--prototype for America's autarchic model of mass production--was being clobbered by the more flexible approach to mass production pioneered by Japan's auto producers. See Abernathy et al. (1983) and Cusumano (1985). In both autos and semiconductors, it is less Japan's low costs and domestic protection than its superior product quality and manufacturing capability which accounts for their victory over U.S. producers.

[30]Cited in M. Schrage, "Hard Times Descend on Silicon Valley," The Washington Post, April 28, 1985.

[31]See Haas (1987) and Stowsky (1987).

[32]Dataquest (1988).

[33]EEPROMs are electronically erasable and programmable read-only memories.

[34]This illustrates the limits of Williamson's (1975) markets-hierarchies dichotomy. If an external contracting relationship is closer than an internal one, internalization is no longer the most efficient way to deal with the costs of uncertainty, small numbers bargaining, and asset specificity.

[35]A Cypress engineer claims, for example, that it is critical that their supplier of ion implanters has a facility located just across the parking lot because it allows them to confer easily and frequently.

[36]LSI Logic, for example, joined with local IC production test equipment manufacturer Asix Systems to develop software for automatic test equipment for ASICs.

[37]Such relationships require geographic proximity, hence ASIC firms like LSI Logic and VTI have design centers near their main customer bases around the world. It also accounts for the continued strength of U.S. producers in ASICs, as domestic systems firms are hesitant to share their new product design specifications with Japanese competitors.

[38]There is concern among some analysts that the reliance of design specialists on Asian foundries will lead to a net transfer of U.S. technology (as happened with memory chips, for example). However this overlooks the difference between semi-custom and specialty products and commodity devices. On one hand, we have seen that semi-custom and specialty chipmakers build very close relations with their customers which helps to protect them from imitators. On the other hand, these specialist producers are continually introducing new designs, so that by the time an imitation is completed the design is often obsolete.

Moreover, some of the most successful design firms, such as Weitek and Altera, use domestic foundries--and firms like IDT, Cypress, Saratoga, and Performance Semiconductor have located fabrication facilities in U.S. (largely within Silicon Valley) to ensure rapid and frequent feedback between design and production.

[39]See McKenna (1989) on the fragmentation of the computer industry.

[40]Contract manufacturers are not only getting involved in the early design process by not only manufacturing the boards but also assembling them into finished systems.

[41]Hence the geographic clustering of firms in Silicon Valley is not driven simply by the desire to reduce transaction costs through proximity, as Scott and Angel (1987) assert, but involves the creation of trust and goodwill which cannot be easily captured by analysis of costs.

[42] "How Apple buys electronics," Electronics Purchasing, November 1986.

[43]These firms are also learning from their employees--a key element in these collaborative relationships which is not discussed here. The "H-P Way," which accords substantial autonomy and responsibility to employees, has been adopted by some of the most successful firms in the region. In addition, new firms like Cypress, IDT, and Sun are deliberately organized to promote cross-functional interchange and horizontal flows of information.

[44]Of the big three in Silicon Valley, only Intel--which has capitalized on its design expertise and on its control of the proprietary personal computer market for microprocessors--is doing well. AMD and National Semiconductor remain in weak competitive positions despite horizontal consolidation (AMD acquired Monolithic Memories and National Semiconductor acquired Fairchild). All three have sought to become more flexible and move into new markets such as ASICs, with only limited success.

[45]More than 18,000 high-tech jobs were created in the region in the twelve months between June 1987 and 1988 alone, and employment surpassed pre-1985 levels. San Jose Mercury News, July 11, 1988. Comparative data from Grubb & Ellis (1987).

[46]LSI Logic is the one exception. It joined Sematech because it could afford to, being much larger than most other start-ups, and because LSI founder Wilf Corrigan is a close personal friend of the founders of Sematech. In many ways, LSI represents the bridge between the old and the new, socially and strategically. Not only is Corrigan one of the last of the original Fairchild team, but while LSI pursued more specialized production in ASICS, they quickly became a high-volume commodity business.

[47]Models for such collective research institutions do exist in U.S. experience. In the 1950s and 1960s, Bell Labs, through leadership in semiconductor research and open diffusion of technological findings and personnel, served as a "national applied research and development laboratory" (Borrus, 1988).

[48]During its first several decades, the AEA was not at all like the traditional American trade association, which focuses on lobbying Washington for beneficial legislation. The AEA grew by creating bottom-up regional councils based in high-tech centers around the country--in order to promote grassroots mobilization and networking. In fact, the AEA only opened a Washington office in 1984.