

Regional Networks and the Resurgence of Silicon Valley

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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

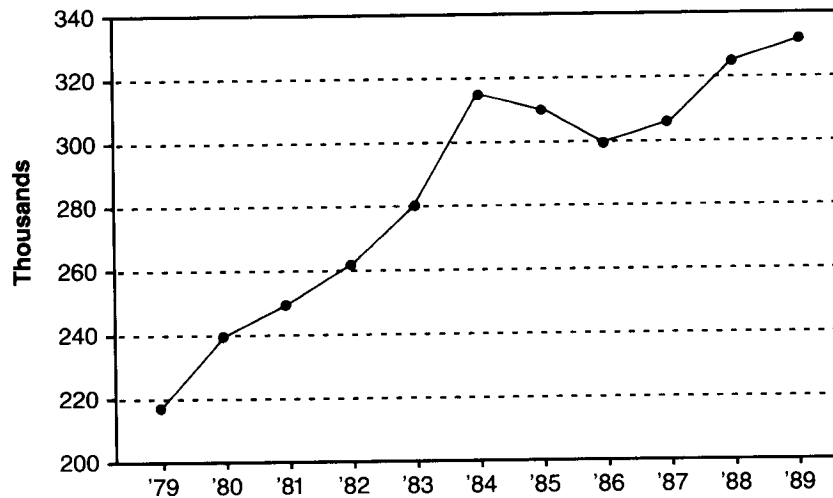
producers saddled with massive overcapacity and declining profits. Between 1984 and 1986, local chipmakers' sales fell 35%, forcing them to lay-off more than 7,000 employees while linked sectors eliminated another 20,000 jobs in the region.¹ Observers, drawing parallels with Detroit and Pittsburgh, were quick to predict the demise of Silicon Valley.

Despite this battering, more than 85 new semiconductor firms were started in Silicon Valley during the 1980s. This new wave of 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% a year and only a handful have failed. Firms in the computer systems and related businesses are also flourishing and regional high-tech employment has surpassed pre-recession levels (see Table 1).

The dynamics of Silicon Valley's revitalization are reflected in this new wave of semiconductor start-ups. These firms, together with hundreds of neighboring technology firms, are forging a flexible model of production in the region. By building on the social networks and industrial infrastructure which were created and then abandoned by the established semiconductor

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Table 1. Santa Clara County High Tech Employment**Number of Employees, 1979-1989**

Source: California EDD, ES202 Series

firms, these small and medium-sized enterprises are pioneering a new Silicon Valley—one which fosters collaboration and reciprocal innovation among networks of specialist producers.

Although public attention is currently focused on trade policy and Sematech, the resilience of the Silicon Valley economy underscores the importance of regional economies to industrial competitiveness and the need for local industrial policy in the 1990s.

Reinterpreting Silicon Valley

The experience of Silicon Valley during the 1980s suggests that the current debate over the future of America's high-technology industry is miscast. 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 entrepreneurial 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 self-reproducing and suggests that increased entrepreneurship is the solution to America's industrial woes. Yet they cannot account for the current weakness of U.S. commodity producers relative to Japan's giant integrated firms. Nor can they explain the failure of regions around the world to replicate the Silicon

Valley experience, even after ensuring free 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 Asian adversaries, 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—suggests the need to reconsider this approach as well.

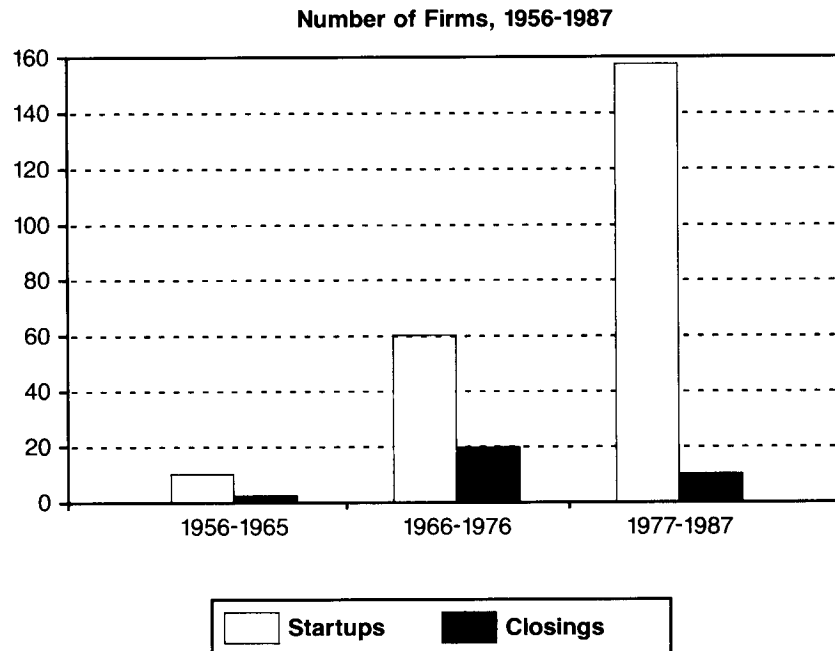
Despite their differences, these opposing approaches place individual firms and national governments at the center of their analyses. As a result, neither can account for the resilience of the Silicon Valley economy: it is a product of the region's dense networks of social, professional, and commercial relationships, not simply of unfettered markets or national policy.

A more fruitful approach begins with the regional economy. Silicon Valley is best viewed as an American variant of the industrial districts of Europe—technologically dynamic regional economies in which networks of specialist producers both compete and cooperate in response to fast-changing global markets. In these districts, technical skill and competence are widely diffused, small and medium sized firms achieve external economies through complex supplier and subcontracting relations, and the region (not the firm) is the locus of production. The result is a decentralized system which is more flexible than the traditional vertically integrated corporation.⁵

While the resurgence of Silicon Valley demonstrates the adaptive capacities of this decentralized productive system, the semiconductor crisis also underscores the vulnerability of industrial districts in the American context. Although the new semiconductor producers are better organized to respond to volatile markets and technologies than their predecessors, they have yet to recognize the social basis of their dynamism and create institutions which allow them to respond systematically to shared challenges.

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.⁶ Entrepreneurs like Cypress Semiconductors' T.J. Rogers and Chips & 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.⁷ They also created the

Table 2. U.S. Semiconductor Startups and Closings

Source: Dataquest, Inc. 1988

largest wave of semiconductor start-ups in the industry's history (see Table 2).

These firms pioneered a flexible approach to semiconductor production—one well adapted to the market conditions of the 1980s. They unbundled production in order to remain focused and to share the costs and risks of developing new semiconductors, and they adopted flexible design and manufacturing technologies that have enabled them to introduce products rapidly and avoid the price wars which periodically plague commodity production.

While the region's established firms—such as Advanced Micro Devices (AMD), National Semiconductor (NS), and Intel—produced standard, general purpose semiconductors (such as commodity memories and microprocessors for mass markets),⁸ the newcomers have focused on high-performance, high value-added components, including custom and semicustom chips as well as standard parts designed for narrow niche markets (semi-standard chips).⁹ Specialist producers such as Cypress Semiconductor, Cirrus Logic, and Maxim Integrated Products emphasize product design, quality, and customer service—not simply low cost.

By 1987, for example, Cypress manufactured over 75 different high-performance products on a single flexible manufacturing line. While few of these individual products were large or stable enough to attract a major competitor, they collectively represented a \$1.4 billion market—comparable

to the market for 256K DRAMS. Today, the firm produces 159 products in seven distinct product areas, basic products, and its 50 packaging options yield close to 1000 distinct variants.¹⁰ Maxim Integrated Products has similarly broken from industry tradition by developing an average of 67 new products every year since its founding in 1983.¹¹

These specialization strategies were often the result of trial and error rather than foresight. Seeq Technology, for example, lost \$35 million and was forced to lay off half of its work force in 1985 as a result of Japanese competition in EPROMs. It was only under these crisis conditions that Seeq withdrew from the commodity memory business and focused on specialty memory and logic products with electrically reprogrammable qualities (such as high-speed EEPROMs). By the end of 1987, the firm had completed an impressive turnaround, with annual revenues up 46% and three consecutive profitable quarters.

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 “minifabs” which process short runs (small wafer lots) of different designs quickly and economically on a single line. This is achieved through the use of modular fabrication lines, which rely on tiny equipment islands scattered throughout the plant to achieve maximum flexibility. While the traditional “mega fab”—optimized for very high throughput of a single design—can cost more than \$250 million and take 2-3 years to build, a “minifab” can be built in 6 months for \$20-50 million.¹² As a result, in 1985 Silicon Valley start-ups produced an average of 100-200 different types of chips on the same line with production runs ranging from 10 and 10,000 units. The large U.S. producers, by contrast, produced 10-20 different commodity memory or logic devices on a line, with runs of one millions units.¹³

The Cypress fab in Silicon Valley exemplifies flexible semiconductor manufacturing. The fab, which was built for a total capital investment of \$36 million, manufactures over 100 different devices using 26 different process technologies. Its very short fab cycle times of about six weeks (compared to more than 16 weeks at a typical U.S. semiconductor manufacturer) allow the company to respond rapidly to changing market conditions. Moreover, by keeping assembly in the region, Cypress has maintained a four-day assembly cycle time (compared to six weeks for the large semiconductor firms which use offshore assembly.)¹⁴

Electronic design automation (combining advances in computer-aided design, engineering, and testing) further enhances the flexibility of the new producers as chip and systems designers are increasingly able to implement their ideas directly onto silicon. Custom and semi-custom integrated circuits now can be designed in weeks rather than months, while complex niche products at the very large scale integration (VLSI) level are being developed in months rather than years.

Finally, these start-ups have spread the prohibitive costs of chipmaking and further shortened their time-to-market by unbundling the production process. 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, Altera and Chips & Technologies specialize in chip design alone and avoid the expense of a fabrication facility by subcontracting manufacturing. Others, including Cypress and Integrated Device Technology (IDT), specialize in leading-edge process technologies and design-process integration. Application specific integrated circuit (ASIC) producers such as LSI Logic and VLSI Technology assist systems firms to design semicustom chips which they in turn manufacture. And still others, such as Orbit Semiconductor, serve solely as quick turnaround, high-performance manufacturing foundries for chip and system houses.

This unbundling promotes technological upgrading. Each firm remains at the leading-edge of its particular expertise—be it chip design, fabrication processes, engineering and design services, or fast turnaround manufacturing—and has access to the products and services of equally sophisticated and specialized suppliers. Cypress founder T.J. Rodgers has even chosen to grow his company through internally funded start-ups rather than risk the loss of focus. Thus the \$200 million company now consists of five relatively autonomous enterprises, each with a distinct technical mandate, which are linked by common strategy, vision, and management systems.

The successes of these 1980s start-ups demonstrate that neither scale nor vertical integration is necessary to survive in the increasingly capital-intensive semiconductor industry. These organizational and technological changes have allowed Silicon Valley's highly focused chipmakers to introduce state-of-the-art products faster than their more integrated competitors. While new product lead times in the industry traditionally exceeded 2 years, firms like Cirrus Logic have shortened development times to nine months.¹⁵ This capability is crucial to compete in markets which require new product introductions every 12 to 18 months.

In short, while the region's established producers sought to mass produce general purpose, commodity devices, the new Silicon Valley chipmakers compete by getting to market first with a continuing flow of specialized products. These start-ups are organized to develop state-of-the-art products and processes and to target technological "windows of opportunity," rather than to pursue the high volumes required to move down the "learning curve" and reduce unit costs on standardized parts.

As they continue to introduce differentiated new products, the specialist chipmakers further fragment semiconductor markets. In the words of Weitek's Vice President of Marketing, John Rizzo:

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.¹⁶

And as fast-growing demand for semi-custom products such as gate arrays turns them into commodities, ASIC firms such as LSI Logic have responded by designing higher performance products for narrower, more specialized niches. Even the prototypical commodity market, standard memories, is being segmented by a proliferation of specialized niche products which are more tightly coupled to particular applications or systems.¹⁷

While commodity chips generated 80% of industry revenue in 1983, their share had fallen to 40% by 1988.¹⁸ This change, referred to by one investment analyst as a “structural shift in the semiconductor industry away from a commodity-driven business,”¹⁹ is forcing the established producers to become more flexible. Even National Semiconductor, long known as a producer of commodity “jelly beans,” is now replacing its standard, off-the-shelf parts with high-margin, proprietary devices. And while the attention of policy makers is focused on the declining share of U.S. producers in commodity markets, Silicon Valley’s specialist chipmakers continue to dominate in high-performance, high value-added and customized semiconductors.

The Importance of Regional Networks

These strategies allowed firms such as 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 merely 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 technical and institutional infrastructure and its dense networks of social and professional relationships. Their successes, like those of their predecessors, are inseparable from a regional environment that is not only rich in skill and know-how, but one which fosters new firm formation and collective learning.

Ironically, the region’s established producers helped create this infrastructure during the 1950s and 1960s, but abandoned it in the 1970s as they shifted to high-volume production. They came to view regional traditions of information sharing and networking as signs of immaturity rather than sources of dynamism, and they distanced themselves from customers and suppliers as they standardized products and processes. The 1980s start-ups, by contrast, are formalizing collaborative relationships with customers and suppliers, both within and outside of the region.

Building on the Informal Networks—When Wilf Corrigan resigned as chairman of Fairchild Semiconductor in 1979, he began to sound out former customers and colleagues on the market for semicustom integrated circuits. Fairchild had abandoned its custom chip business in the early 1970s, but Corrigan sensed a renewed opportunity. He encountered a former employee, Robert Walker, who had recently completed research for an article on the

state of the custom chip business. Walker joined Corrigan to write a business plan for a firm called LSI Logic Corporation (to focus on semicustom chips) and together they secured financing from some of Silicon Valley's leading venture capital firms, including former colleagues at Kleiner Perkins.

The two then recruited a team of engineers from the group that Walker had worked with on CAD and custom chips at Fairchild during the 1960s. Calling themselves the "over the hill gang," this new team relied on the region's extensive infrastructure of market research firms, public relations specialists, technical consultants, and trade associations for assistance. 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.

Similar entrepreneurial histories are commonplace in Silicon Valley, where dense social networks and local institutions foster the recombination of experience, skill, and technology into new enterprises. Several hundred new technology firms were formed annually in the region during the 1980s, including two out of every three of the nation's semiconductor start-ups.²⁰ These firms are unusually resilient. A recent study concluded that while only 75% of U.S. manufacturing start-ups survive their first two years, 90% of Silicon Valley manufacturing start-ups survive their first *six*.²¹ As a result, by 1989 the region was home to 4,800 technology establishments, which employed more than 300,000 workers.²²

It is not simply the concentration of skilled labor, suppliers and information that distinguish the region (as traditional economic accounts would have it).²³ A variety of regional institutions—including Stanford University, several trade associations and local business organizations, and a myriad of specialized consulting, market research, public relations and venture capital firms—provide technical, financial, and networking services which the regions' enterprises often cannot afford individually. By socializing costs and risks and pooling technical expertise, these institutions allow Silicon Valley's specialist firms to continue to innovate and react flexibly.

Venture capitalists are central to these networks. In fact, the venture capital industry in Silicon Valley was created by successful high-technology entrepreneurs who chose to reinvest their earnings in promising local start-ups—not the reverse, as frequently assumed. Today more venture capital is invested in Silicon Valley than elsewhere in the United States: in 1985, for example, local firms received \$800 million in venture capital, compared to just over \$300 million each in Massachusetts and Southern California, and under \$200 million in Texas.²⁴ And because many of Silicon Valley's most prominent venture capitalists continue to come out of successful local companies, they are able to contribute not simply cash but also years of experience and contacts to new ventures.²⁵

Equally important are the social relationships that develop with shared professional experiences and repeated interaction.²⁶ When John Gifford founded Maxim Integrated Products in 1983 he had already been involved

in six different start-ups in his twenty-five year career.²⁷ This is not uncommon in Silicon Valley, where engineers are often more loyal to the industry and advancing technology than to an individual firm. In the words of LSI's Walker:

Here in Silicon Valley there's far greater loyalty to one's craft than to one's company. . . . A company is just a vehicle which allows you to work. If you're a circuit designer it's most important for you to do excellent work. If you can't in one firm, you'll move on to another one.²⁸

As individuals move from firm to firm in Silicon Valley their paths overlap repeatedly: a colleague might become a customer or a competitor, today's boss could be tomorrow's subordinate. Professional respect, loyalties, and friendships transcend this turmoil.

These networks defy sectoral barriers: individuals move easily from semiconductor to disk drive firms or from computer to network makers. They move from established firms to start-ups (or vice versa) and even to market research or consulting firms, and from consulting firms back into start-ups. And they continue to meet at trade shows, industry conferences, and the scores of seminars, talks, and social activities organized by local business organizations and trade associations. In these forums, relationships are easily formed and maintained, technical and market information is exchanged, business contacts are established, and new enterprises are conceived.

Moreover, these forums help to reproduce the "sense of community" which distinguishes the region. A shared commitment to advancing technology—derived originally from the common formative and professional experiences of engineers in the region—transcends inter-firm rivalries.²⁹ This social cohesion is reflected in the poster of the Silicon Valley "family tree" which hangs on many walls in the region (a genealogy of the scores of start-ups descended from Fairchild Semiconductor) and in frequent references to firms or individuals as "grandfathers" or "offspring."³⁰

Although it is no longer true that "everyone knows everyone" in Silicon Valley, executives still regard the density and openness of the region's social and professional networks as a distinct advantage. Those who have worked elsewhere concur that the extent of informal exchange in Silicon Valley surpasses even other U.S. centers of technology industry such as Route 128 in Massachusetts and Austin, Texas.³¹ Technical and market information thus diffuse rapidly among customers, suppliers, and competitors within the region, continually paving the way for new opportunities and enterprises.

This decentralized and fluid environment also promotes the diffusion of intangible technological capabilities and understandings. When individuals move between firms (and even sectors) in the region, they carry the tacit knowledge which is specific to a particular production process—and which cannot be bought or sold, or even written down. In fact, IDT's Larry Jordan claims that a distinct language has evolved in the region and that certain

technical terms used by semiconductor production engineers in Silicon Valley would not even be understood by their counterparts in Boston's Route 128. The localization of technical know-how and skills encourages an ongoing process of learning by problem solving among the region's semiconductor and computer firms and the variety of linked industries.

This is not to suggest that conflicts are absent in Silicon Valley. It is the very intensity of competition among local producers that spurs the technological innovation for which the region is famous. In fact, competitive rivalries often become highly personalized, as status is defined by technical excellence and innovation as much as by market share. Lawsuits and conflicts over intellectual property are now commonplace. Yet even as these competitive pressures intensify, the sense of loyalty and shared commitment to technological excellence unifies the members of this industrial community.

Thus while Silicon Valley's high rates of inter-firm mobility and new firm formation may lead to losses for individual firms—as suggested by critics like Ferguson—it also fosters a dynamic process of industrial adaptation. The region as a whole benefits from an ongoing process of experimentation and collective learning as new ideas are continually recombined with existing skill, technology, know-how, and experience.

“Outgrowing” the Networks—The competitive difficulties of the region's established semiconductor producers—the “fathers” of Silicon Valley—demonstrate the importance of these networks. The companies which made Silicon Valley famous for their responsiveness and innovation withdrew from the networks in their shift to commodity production. Fairchild Semiconductor was not alone when it closed its computer-aided-design business in 1974: virtually all of the region's large firms rejected specialty and custom production in favor of standard products in the same period (thus infuriating small and medium-sized computer systems customers who depended on custom chips but could not afford to produce their own).³²

By the late 1970s, the growing threat of low-cost Japanese producers led firms such as National Semiconductor, Intel, and AMD to invest heavily in dedicated, high-volume fab lines in order to reduce their unit costs. In fact, domestic semiconductor manufacturing capacity doubled between 1978 and 1980 as capital expenditures increased from eight to twenty percent of sales.³³ Silicon Valley's chipmakers quickly “matured”—changing from small, flexible enterprises into large and bureaucratic commodity-oriented corporations. This led many observers to predict an end to start-ups in the semiconductor industry.³⁴

Failing to recognize the importance of the region and its relationships to their past successes, the merchant semiconductor firms chose an autarkic approach to mass production. As they standardized products and processes to achieve high-volume output and move down the “learning curve,” they saw little need for the ongoing interaction with customers, suppliers, and competitors that had characterized specialty production.³⁵

In 1979, Intel co-founder Andrew Grove articulated the industry consensus when he announced that the task for the 1980s was to “market pre-fabricated mass produced solutions to users.”³⁶ Intel soon became infamous for its arrogant “take it or leave it” attitude toward its customers.³⁷ By 1987, a prominent venture capitalist observed that “the customer has become a distant entity to the merchant semiconductor producers.”³⁸ As a result, firms such as NS, AMD, and Intel missed a series of key technical and market opportunities, including the CMOS process, ASICs, and chip sets. They also began losing customers to the more responsive Japanese producers.

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. As they geared up for high-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 played key vendors against one another for price reductions. This reinforced the tendency of the financially weak equipment makers to ship products which were not fully debugged, and eliminated the trust needed to jointly refine and improve the complex process of manufacturing semiconductors. Recent research suggests that the inferior quality and lower yields of U.S. semiconductor producers relative to their Japanese competitors was a direct result of this arm’s-length relationship.³⁹

Even the informal cooperative practices of the 1960s and 1970s such as cross licensing and second sourcing were largely abandoned. Ignoring their own genesis, the merchants initiated lawsuits against former cross-licensees, 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 relocated wafer fabrication facilities to lower-cost areas within the U.S. It appeared that only high-level research, design and prototype production would remain in 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.⁴⁰ Although the problems created by distance can often be overcome by active management, this separation appears to have exacerbated a growing gulf between design and manufacturing.

By pursuing an autarkic version of mass production, Silicon Valley’s leading chipmakers abandoned the flexibility and technological dynamism which had distinguished them in the past. 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.⁴¹

This is not to suggest that the shift to mass production was necessarily mistaken. Silicon Valley's producers could have pursued a successful high-volume production strategy without abandoning the regional networks. Like the Japanese, they would have organized themselves to learn from their customers and equipment suppliers and maintained close ties between product development, manufacturing, and assembly.⁴² By adopting an autarkic version of mass production just as the Japanese were refining a highly integrated approach however, Silicon Valley's merchant producers fell behind in customer relations, manufacturing improvements and product quality and quickly lost market share to Japanese competitors.

Formalizing the Networks—Silicon Valley's 1980s start-ups, by contrast, are not simply building on the region's social and professional networks—they are formalizing them. Firms such as Cypress, IDT, and Weitek have rejected the arm's-length relations of the commodity producers, and are building partnerships with customers and suppliers in order to monitor changing markets and jointly redefine products and processes.

The proliferation of strategic alliances in the industry is one clear indication of this reorientation. Semiconductor start-ups have forged more than 350 alliances since 1979, mostly involving technology sharing, subcontracting of chip fabrication, or joint product development.⁴³ In many cases, start-ups are collaborating with one another, as in the alliance between Cypress and Altera to jointly develop high-density EPLDs. In other cases a start-up teams up with a larger firm, as in the technology-licensing and manufacturing agreement between Seeq and National for high-density EEPROMS.

In a highly publicized case which typifies these partnerships, Hewlett-Packard opened up its state-of-the-art foundry for the first time to chip design specialist Weitek to manufacture a very high speed data-crunching chip. As a result, H-P now differentiates its workstations with a higher speed chip than it could have bought or designed in-house, while Weitek markets this sophisticated chip to other systems makers. Both firms see the relationship as paving the way for a succession of future joint efforts and technology exchanges.

These relations between chipmakers and their subcontractors are blurring the boundaries between independent firms. H-P sees itself as an extension of Weitek's manufacturing, in spite of the great differences in the size of the two firms. According to Jeffrey Miller, Vice President of Marketing at semiconductor producer Adaptec:

Our relationship with our vendors is not much different than my relationship was at Intel with our corporate foundry—except that now I get treated as a customer, not as corporate overhead. . . . It really is very hard to define where we end and where our subcontractors begin.⁴⁴

Many start-ups are working closely with their equipment makers as well. Cypress engineers claim, for example, that it is critical that their supplier of ion implanters is located just across the parking lot because it allows them to confer, adjust complex processes, and trouble shoot easily. Others report collaborating with wafer stepper and automated test equipment producers to design and de-bug products which allow for rapid product change and reduced equipment set-up times. LSI Logic, for example, jointly develops automatic test equipment software for ASICs with local equipment maker Asix Systems.

Finally, the new chipmakers are building partnerships with customers in the computer systems industry. ASIC producers must work very closely with their customers in order to help them design semicustom circuits. But even producers of semistandard products like Cypress and IDT treat customers as extensions of their organizations in order to keep up with the accelerating pace of new product introductions and define products for highly focused applications. Alliances with trend-setting computer firms allow the chipmakers to stay apprised of fast-changing systems requirements and target emerging niches rapidly.

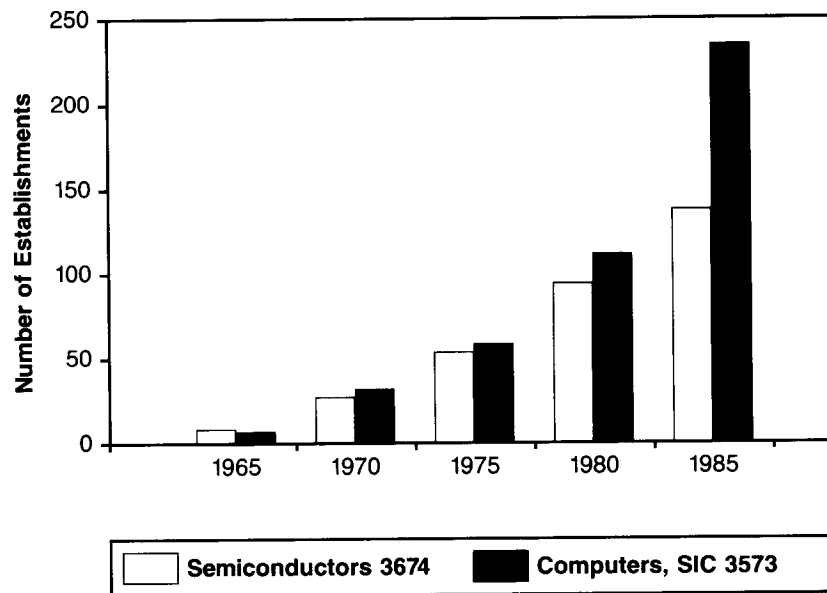
Design specialist Weitek is so committed to building close ties with customers that it maintains one applications engineer for every field salesman, compared with an engineer for every 16 salesmen at a traditional firm. The firm's Vice President of Marketing, John Rizzo, explains that he learned the importance of collaboration only after leaving Intel (where customers were largely ignored) to work for Apple Computers (where he gained the customer's perspective). At Weitek, he claims:

We're trying to build an intangible emotional bond and loyalty between ourselves and the customer. Those intangible bonds are the hardest things for a competitor to break.⁴⁵

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 partnerships is with Texas-based Compaq and H-P is jointly developing its RISC microprocessor with Hitachi. In addition, many Silicon Valley semiconductor start-ups subcontract manufacturing to fabs in Japan, Taiwan, and Korea.⁴⁶ Yet proximity greatly facilitates the collaboration required for fast-changing and complex technologies which involve ongoing interaction, mutual adjustment, and learning.

The Creation of Regional Production Networks

The success of Silicon Valley's specialist semiconductor producers is inseparable from the growth of the computer systems producers that now dominate the region (see Table 3). New computer producers such as Silicon Graphics, Sun Microsystems, and Mips Computers, along with established

Table 3. Semiconductor and Computer Firms**Santa Clara County, 1960-1985**

Source: County Business Patterns

firms such as Hewlett Packard, Tandem and Apple are now at the center of the region's emerging production networks.⁴⁷ As these systems firms rely increasingly on custom and specialized parts to differentiate their systems, they are being drawn into collaborative relations with networks of suppliers both within and outside of the region.

Sun Microsystems typifies the new systems firms: they design their own products and software and perform limited printed circuit board manufacturing and final assembly in-house; they subcontract or purchase the rest of their inputs, including ASICs, disk drives, terminals, power supplies, and networking hardware. Even the microprocessor at the heart of Sun's workstation is manufactured externally. By unbundling production and collaborating with subcontractors and suppliers, these systems firms share the costs and spread the risks of new product design and production, reduce their time to market, and increase the frequency of new product introductions. Sun, for example, introduced four major product generations in its first five years of business. This accelerating pace of new product introductions in turn has forced both start-ups and established systems producers to become more flexible.

Take the case of Mips Computer Systems. Mips was formed in 1984 to produce RISC-based microprocessors and computer systems. Despite its

state-of-the-art microprocessor, Mips was nearly bankrupt by 1987, unable to sustain the cost of maintaining a semiconductor fab and innovating in chips, boards, and systems simultaneously. A new management team chose to focus solely on system-level design and to rely on independent semiconductor producers to manufacture, market, and support their RISC chips. According to the Vice President of Marketing at IDT (one of the sub-contractors):

The concept is that Mips is the hub and each of the partners are spokes on the wheel. . . . Each of the partners shares equally in the product knowledge and product evolution.⁴⁸

Managers at other Silicon Valley firms similarly describe their relations with suppliers and subcontractors as partnerships, increasingly between equals. While some like H-P and Apple began by pursuing the cost reductions and quality improvements of just-in-time production, they are now building long-term and trust-based relationships—particularly with suppliers of technically complex and fast-changing components.

This represents a radical departure from past practices of seeking the lowest-cost supplier to meet pre-defined specs. Both customers and suppliers describe mutual commitments not to abandon each other during downturns or to exploit advantages during upturns. Many work to ensure that their suppliers survive hard times. For example, when several of Adaptec's major customers went out of business simultaneously, a key supplier extended credit to the firm, enabling it to stay in business. Other firms help identify new customers for their suppliers during tough periods.

The best of these partnerships evolve into highly interactive relationships with two-way flows of information, extensive technology exchange, and joint problem solving. 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, shared funding of key engineering talent, and technology exchanges, 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."⁴⁹

In short, the process of solving problems and charting future directions in a technologically volatile environment is increasingly a cooperative effort by networks of linked firms. 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 RISC microprocessor, the boundaries of these firms begin to blur.

Despite this blurring of firm boundaries, however, both customers and suppliers make an explicit effort to avoid dependence and to preserve one another's autonomy. Most Silicon Valley companies today prefer that no

customer, itself included, account for more than 20% of a supplier's output. These limits on dependence ensure that while firms benefit from collaboration in a shared goal, they do not become so tightly integrated as to lose the competitive spirit to innovate.

This is not to imply that all supplier relations in Silicon Valley are collaborative: computers still use large numbers of commodity semiconductors such as DRAMS and capacitors which are purchased in volume from the lowest-cost producers (often Asian). Moreover, there is a wide range of technologically unsophisticated parts—such as boxes and cables—which are competitively sourced without extensive relationship building.

However, as collaboration extends to a wider circle of firms, it generates a process of complementary innovation between networks of autonomous but interdependent producers in Silicon Valley. Not only do they spread their risk by serving a diversified customer base, but suppliers share the learning and know-how gained from serving a customer in one sector with customers in other industries. Collaboration thus both intensifies competitive pressures and contributes to the technological vitality of the region, ensuring that, in the words of Sun's purchasing director Scott Metcalf, "the world's best suppliers of technology products are in Silicon Valley."⁵⁰

The process of reciprocal technological upgrading is clear in the transformation of the contract manufacturing industry. Flextronics, one of the region's largest contract manufacturers, grew explosively during the 1980s as it shifted from being a consignment assembler (a classic job shop) to a full turnkey assembler assisting with design and supplier selection as well as assembly and testing of printed circuit boards. As more systems firms subcontract manufacturing, the contract manufacturing industry is changing from low-skill, labor-intensive assembly to a high-skill, capital-intensive business. In fact, by investing in new technologies (such as surface mount technology) and serving customers in a variety of businesses, firms such as Flextronics and Solectron have achieved a level of manufacturing expertise unsurpassed among systems producers in the Valley.

Collaborative relations are 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. Robert Todd, CEO of Flextronics, claims that in his business, true collaboration cannot survive over great distances for long because of the continuous need to adapt jointly to unanticipated contingencies. 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.⁵¹

The need for continual interaction—particularly in a period of market volatility and rapid new product introduction—thus motivates firms to continue

clustering in Silicon Valley, in spite of its exorbitant housing prices and high labor costs. Intensified regional concentration thus accompanies the ongoing internationalization of production.

Conclusion

Today, Silicon Valley is flourishing. While the performance of individual technology firms varied considerably during the 1980s, employment increased by more than 35%. The region's specialist producers continued to dominate growing markets for high-performance microprocessors, logic and memory chips, and computer systems. And as both new and established firms prosper, the geographic boundaries of the region expanded beyond Santa Clara County, spilling north into San Mateo, east into Fremont and south to Santa Cruz.⁵²

Silicon Valley's resilience owes as much to its rich networks of social, professional and commercial relationships as to the efforts of individual entrepreneurs. The informal cooperation which promoted the diffusion of technology and know-how during the 1960s and 1970s was formalized through partnerships in the 1980s. Paradoxically, both cooperation and competition are intensifying as local firms organize themselves to learn with their customers, suppliers, and competitors about what to make next and how to make it.

However, the industrial fragmentation that is a source of Silicon Valley's flexibility and dynamism also represents its greatest vulnerability. There is no forum in the region for the administrative coordination and strategic planning which is achieved by the management of a vertically integrated firm. Individual firms cannot stay fully abreast of the rapid pace of market and technological change, nor can the evolving system of inter-firm supplier networks in Silicon Valley substitute for systematic, long-range planning.

The U.S. trade deficit in electronics has dramatized both the need for an industrial strategy in Silicon Valley and the absence of institutions to coordinate one. The region's venture capitalists, consulting firms, business organizations, and universities are largely private and narrowly specialized, and the local public sector is focused exclusively on providing the physical infrastructure for development. As a result, there is no vehicle for developing a regional response to shared challenges such as shortages of engineers or external technological shifts.

This institutional vacuum reflects the longstanding distrust of the public sector in Silicon Valley. The industry's early leaders were explicitly hostile toward the activities of large firms, banks, and government of any sort. In an environment of rapid and sustained growth, there was little need for collective action. Even today's entrepreneurs describe their successes in George Gilder's language of individualism and entrepreneurship, failing to recognize the importance of the region and its networks to their continued dynamism.

The semiconductor crisis did politicize a segment of Silicon Valley. In 1978, the region's commodity chipmakers formed the Semiconductor Industry Association (SIA) and, in response to heightened Japanese competition, abandoned their laissez-faire views. Unlike the established trade associations in the region, the American Electronics Association (AEA) and the Semiconductor Equipment Manufacturers International (SEMI)—which were oriented toward providing technical, educational and market services for small and medium-sized technology firms—the SIA devoted its attention exclusively to lobbying Washington for favorable trade and tax legislation and other federal support.

Although it represents only a handful of the region's technology firms, the SIA succeeded in establishing itself in the public eye as the representative of Silicon Valley—even of American technology industry. But once again, the established semiconductor firms overlooked the importance of the region's networks. The initial "victory" of the SIA in attaining the semiconductor trade agreement with Japan in 1986, for example, alienated the region's computer systems firms, who resented the dramatic price increases for memory chips and the subsequent memory shortages.⁵³ Nor did it win the support of the rest of the Silicon Valley community, including most of the semiconductor start-ups. Moreover, by the late 1980s, the AEA had accepted the SIA's definition of competitiveness as a sectoral problem which could be solved only at the national level, and redirected its resources away from local management education and training programs towards lobbying the federal government.

Sematech, the collaborative semiconductor manufacturing consortium, also has limited promise as an industrial strategy for Silicon Valley because its membership is severely restricted. Only 14 of the 293 semiconductor producers in the U.S. are members of Sematech and none of Silicon Valley's recent start-ups have joined the consortium because its prohibitive fees exclude all but the largest firms.⁵⁴ In addition, several of the region's equipment manufacturers have recently discontinued their participation in SEMI/Sematech (which represents 84 U.S. equipment and materials vendors to Sematech), claiming that it favors large firms over small and is too expensive.⁵⁵ As a result, critics like Cypress's T.J. Rogers view Sematech as a bailout for aging semiconductor companies.⁵⁶ While carefully designed joint research projects could help to preserve the technological position of the U.S. semiconductor industry, a program which excludes so many of the industry's most innovative producers is unlikely to do so.

Silicon Valley needs public forums for debating regional industrial strategies and defining institutions to ensure the flexibility and dynamism of its networks of specialist firms. These institutions should preserve the openness of the region's social and commercial networks and ensure the continuing exchange of information, experience, and technology across industry boundaries and between firms of all sizes. They should enhance the ability of

local firms to continually innovate, learn, and adapt to changing conditions—rather than protecting them or isolating them from change.

These institutions might ensure that the region's firms: have access to long-term financing and recent research findings; coordinate technical and managerial training programs and basic research projects; provide export and marketing assistance and global information-gathering services; organize data collection and analysis of the region's fast-changing industrial base; and establish forums for joint assessment of sectoral or regional problems. With time, they would provide a forum for defining and coordinating responses to external developments such as unanticipated technical advances and competitive challenges from outside of the region.

Trade associations in Silicon Valley already perform some of these activities. Local economic development agencies and business organizations could take on others. Others would require the creation of entirely new institutions, which can only develop out of public dialogue and debate.⁵⁷ To begin such a dialogue requires that Silicon Valley's entrepreneurs and managers overcome their deep-seated distrust of the public sector and recognize the social basis of their success.

The main challenge facing Silicon Valley today is to transcend the language of individual achievement and build a vocabulary which reflects a recognition of, and commitment to, the region as a key source of industrial competitiveness. Only a carefully considered public dialogue which defines appropriate regional institutions and moves beyond George Gilder's free markets and Charles Ferguson's national industrial policy can preserve the dynamism of the Silicon Valley economy.

Glossary

Application specific integrated circuit (ASIC): An IC designed by or with customers for a particular application. Includes full custom devices and semicustom gate arrays, standard cells, and programmable logic devices.

Central processing unit (CPU): The section of a computer system that controls interpretation and execution of instructions.

Chip set: A set of VLSI devices, designed using ASIC tools, which emulate the function of personal computer but are smaller and faster due to a radically reduced part count.

Complementary metal-oxide semiconductor (CMOS): A manufacturing process which allows ICs to function with far less power and than traditional metal-oxide semiconductors.

Dynamic random access memory (DRAM): The cheapest and least power consuming semiconductor memory which must be electrically refreshed periodically to retain memory.

Electrically erasable and programmable read-only memory (EEPROM): A memory device in which stored information can be erased and reprogrammed electrically while still in the circuit, e.g., from a keyboard.

Erasable programmable read-only memory (EPROM): A memory device in which the stored information can be erased and reprogrammed by exposure to ultra-violet light through a window in the package.

Erasable programmable logic device (EPLD): IC sold as a blank logic device which allows the user, typically a system designer, to customize it to a specific application.

Gate array: An ASIC in which an array of digital logic gates are interconnected to customer specifications to perform a specific function. Typically only the last one or two layers of the circuit are customized.

Integrated circuit (IC): A semiconductor circuit combining the functions of many electronic components in a single monolithic substrate which is usually silicon.

Metal-oxide semiconductor (MOS): Transistors and ICs that utilize metal (or silicon) gate devices insulated by an oxide layer from the semiconductor or silicon channel.

Microprocessor (MPU): A single chip large-scale IC which is the central processing unit of a small computer. It performs all logic and arithmetic operations and controls the operation of the other parts of the system, such as input, memory storage devices, and output devices.

Printed circuit board (PCB): Provides the hundreds of electrical interconnections between the components in a circuit through the flat, thin copper pathways on or embedded within an insulating base material (typically paper or fiberglass).

Programmable logic device (PLD): IC formed of digital logic gates connected together in a matrix and designed to be customized by the user, typically by "blowing" out fusible links.

Programmable read-only memory (PROM): A memory device in which information can be stored after the device is manufactured, but cannot be altered.

Random access memory (RAM): A memory device in which information can be entered into or retrieved quickly from any storage site and which is used to hold temporary information.

Read-only memory (ROM): A memory storage device in which the information is permanently wired into the device, and is used to store permanent instructions.

Reduced instruction set computing (RISC): Microprocessor which executes fewer, less complex instructions than the traditional microprocessor, thus streamlining and accelerating the entire chip.

Static random access memory (SRAM): The fastest and most expensive random access memory device which only loses its stored information when power is shut off.

Standard cell: An ASIC which is created using standard circuit cells arranged in a custom manner to perform specific functions. Closest of all ASICs to full custom.

Surface mount technology (SMT): Automated PCB assembly method in which devices are mounted directly onto the board surface, and which shrinks the board size significantly by allowing manufacturers to fit more devices into the same space.

Through-hole assembly: Conventional printed circuit board assembly method where component leads are pushed into holes through the board.

Yield: A measure of the efficiency of a production process determined by the ratio of acceptable parts completed to the number of parts attempted.

Very large scale integration (VLSI): A term applied to integrated circuit chips containing a minimum of 5,000 logic gates, or more than 16,000 bits of memory.

References

1. "The Chips Are Down," *San Jose Mercury News*, December 1, 1986.
2. Dataquest Inc., "Survey of Semiconductor Start-Ups" (Mountain View, CA: Dataquest, 1988).
3. C. Ferguson, "From the People Who Brought You Voodoo Economics," *Harvard Business Review* (May/June 1988), pp. 55-62; G. Gilder, "The Revitalization of Everything: The Law of the Microcosm," *Harvard Business Review* (March/April 1988), pp. 49-61.
4. See A. Saxenian, "The Cheshire Cat's Grin: Innovation, Regional Development and the Cambridge Case" *Economy and Society*, 18/4 (Winter 1989) for a critique of this free market approach (the "high-tech recipe").
5. These regions are modern counterparts of the 19th century Marshallian industrial districts. See C. Sabel, "Flexible Specialisation and the Reemergence of Regional Economies," in P. Hirst and J. Zeitlin, eds., *Reversing Industrial Decline* (Oxford: Berg, 1988); M. Piore and C. Sabel, *The Second Industrial Divide* (New York, NY: Basic Books, 1984).
6. The research for this project entailed over fifty open-ended interviews with Silicon Valley executives, managers, engineers, and venture capitalists that were conducted between 1988 and 1990.
7. See, for example, T. J. Rogers, "Return to the Microcosm," letter to the editor of the *Harvard Business Review* (July/August 1988), pp. 139-140.
8. While National was traditionally known for emphasizing low-cost production of commodity memories and AMD, Intel, and MMI specialized in design innovation (e.g., in microprocessors), all were oriented toward serving mass markets.
9. For a discussion of the various specialization strategies, see B. Cole, "ASIC Houses Revise Their Strategies," *Electronics*, August 6, 1987.
10. J. Corn and R. Rajaratnam "Cypress Semiconductor and Integrated Device Technology" Needham Investment Analysis, Needham & Co., Inc. April 4, 1990.
11. J. McCreddie and V. Rice, "Nine New Mavericks," *Electronic Business*, September 4, 1989.
12. M. Mehler, "Minifabs Reshape IC Production," *Electronics Business*, June 1, 1987; B. Cole, "Getting to the Market on Time," *Electronics* (April 1989).
13. M. Borrus, *Competing for Control* (New York, NY: Ballinger, 1988).
14. Corn and Rajaratnam, op. cit.
15. McCreddie and Rice, op. cit.
16. Cited in V. Rice, "The Upstart Start-Ups," *Electronic Business*, August 15, 1987.
17. While in 1985 there were only half a dozen basic designs, there are now more than 100 standard memory architectures and options, and the process will continue. B. Cole, "By the Mid-90's the Memory Market Will Look Like the Logic Business," *Electronics* (August 1988).
18. M. Leibowitz, "ASIC Strategies for the Big Five," *Electronic Business*, October 15, 1988.
19. Investment report by Alex Brown & Sons, Baltimore. Cited in J. Goldman, "Nine Valley Chip Companies Recommended by R&D Firm," *The San Jose Business Journal*, October 30, 1989.
20. A. Scott and D. Angel, "The U.S. Semiconductor Industry: A Locational Analysis," *Environment and Planning D*, 19 (1987).
21. 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.

22. *Rich's Business Guide to Silicon Valley and Northern California* (Los Altos, CA: Rich's Business Directories, 1989).
23. See, for example, P. David and J. Rosenbloom, "Marshallian Factor Market Externalities and the Dynamics of Industrial Localization," Center for Economic Policy Research, Publication No. 118, Stanford University, 1987.
24. *Electronic Business*, 1987.
25. Silicon Valley's venture capitalists are typically intimately involved in the businesses they support: they advise entrepreneurs on business plans and strategies, help find coinvestors, recruit key people to fill out a management team, provide regular (even daily) management advice, and serve on boards of directors.
26. M. Granovetter, "Economic Action and Social Structure: The Problem of Embeddedness," *American Journal of Sociology*, 91/3 (1985).
27. D. Angel, "The Labor Market for Engineers in the U.S. Semiconductor Industry," *Economic Geography*, 65/2 (1986).
28. Interview, Robert Walker, Vice President and Chief Engineering Officer, LSI Logic Corporation, May 2, 1988.
29. Journalistic accounts of Silicon Valley capture this sense of social cohesion. See E. Rogers and J. Larsen, *Silicon Valley Fever* (New York, NY: Basic Books, 1984); M. Malone, *The Big Score* (New York, NY: Doubleday, 1985); E. Braun and S. MacDonald, *Revolution in Miniature* (New York, NY: Cambridge University Press, 1978).
30. A. Saxenian, "A High Technology Industrial District: Silicon Valley in the American Context," in P. Perulli, ed., *Citta della scienza e della tecnologia*, Quaderni della Fondazione Istituto Gramsci Veneto 6/7 (Venice: Arsenale Editrice, 1989).
31. See J. Weiss and A. Delbecq, "High Technology Cultures and Management: Silicon Valley and Route 128," *Group and Organization Studies*, 12/1 (March 1987).
32. As late as the early 1970s, the 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 R. Wilson, P. Ashton, and T. Egan, *Innovation, Competition, and Government Policy in the Semiconductor Industry* (Lexington, MA: Heath, 1980).
33. *Business Week*, July 21, 1980.
34. See, for example, A. Robinson, "Giant Corporations From Tiny Chips Grow," *Science*, 208 (1980).
35. For the classic explanation of the "learning curve" in semiconductors, see R. Noyce, "Microelectronics," *Scientific American*, 237/3 (1977); R. Noyce, "Large-Scale Integration: What Is Yet to Come?" *Science*, 195 (March 1977).
36. Cited in *The San Jose Mercury News*, May 4, 1980.
37. A. Hayashi "The New Intel: Moore Mature, Moore Competitive," *Electronic Business*, November 15, 1987.
38. 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.
39. J. Stowsky, "The Weakest Link: Semiconductor Equipment, Linkages, and the Limits to International Trade," Working Paper No. 27, Berkeley Roundtable on the International Economy, University of California, Berkeley, 1988.
40. C. Markides and N. Berg, "Manufacturing Offshore is Bad Business," *Harvard Business Review* (September/October 1988), pp. 113-120.
41. M. Schrage, "Hard Times Descend on Silicon Valley," *The Washington Post*, April 28, 1985.
42. E. Haas, "Applying the Lessons: Networking Semiconductor Companies," *Entrepreneurial Economy*, 6/1 (July/August 1987); M. Aoki, "The Japanese Firm in Transition," in K. Yamamura and Y. Yasuba, eds., *The Political Economy of Japan* (Palo Alto, CA: Stanford University Press, 1987).

43. Dataquest, op. cit., 1988.
44. Interview, Jeffrey Miller, Vice President of Marketing, Adaptec Corporation, May 10, 1988.
45. Cited in S. Jones, "Hewlett Packard Inks Major Chip Deal," *San Jose Business Journal*, May 18, 1987.
46. Observers often view this reliance on offshore foundries as a fatal vulnerability for the U.S. start-ups. They neglect, however, to recognize that manufacturing is only a minimal part of the total costs (typically less than 10%) of these highly specialized, design-intensive chips. Moreover, imitation is not the same threat that it is for a commodity chip maker: their design cycles are so fast that by the time a competitor had produced an imitation of a chip, their next generation would be available. Finally, it is worth noting that this dependence on foreign suppliers is a direct result of the autarkic behavior of the established U.S. semiconductor firms. Many start-ups report being driven to use Asian foundries by the refusal of domestic producers to provide them with manufacturing fab capacity.
47. A growing literature describes network forms of organization, which fall between market exchange and administered hierarchies. However, most scholars neglect the spatial aspects of these networks. See W. Powell "Neither Market Nor Hierarchy: Network Forms of Organization" *Research in Organizational Behavior*, 12 (1990): 293-336. For a more extensive discussion of the supplier relations of Silicon Valley computer systems firms, see A. Saxenian, "The Origins and Dynamics of Production Networks in Silicon Valley," Working Paper No. 516, Institute of Urban and Regional Development, University of California at Berkeley.
48. Cite in C. Koland, "Mips Chip Coalition Targets Leaders in Microprocessors," *San Jose Business Journal*, December 17, 1987.
49. Cited in M. Cohodas, "How Apple Buys Electronics," *Electronics Purchasing* (November 1986).
50. Interview, Scott Metcalf, Purchasing Director, Sun Microsystems, March 30, 1988.
51. "How Apple Buys Electronics," *Electronics Purchasing* (November 1986).
52. This geographic expansion means that the data presented here on Santa Clara County significantly understates the growth of employment in Silicon Valley, which now includes portions of three adjacent counties.
53. A. Pollack, "Chip Pact Falls Short of Goals," *The New York Times*, August 2, 1988. See also D. Mowery and N. Rosenberg, "New Developments in U.S. Technology Policy: Implications for Competitiveness and International Trade Policy," *California Management Review*, 32/1 (Fall 1989): 107-124.
54. Total entrance fees are about \$2 million. Sematech requires a \$1 million entry fee, and member firms must also join the Semiconductor Research Consortium for a \$62,000 entry fee plus annual dues ranging from \$65,000 to \$2.4 million (depending on firm size). In addition a minimum of 5 engineers must be sent to participate in Sematech activities in Austin. These fees are high even for the established companies (equalling about 10% of their R&D budgets), but they are prohibitive for small firms; moreover, most start-ups can't afford to lose five of their best people. LSI Logic is the only Silicon Valley start-up that belongs to Sematech. It joined because it could afford to (being much larger than other start-ups) and because LSI founder Wilf Corrigan is a close personal friend of the founders of Sematech.
55. V. Rice, "The Decline of Chip Equipment Firms," *San Jose Mercury News*, December 4, 1989.
56. Cypress president T.J. Rogers claims that "Sematech is a carefully constructed lobby effort . . . to deliberately and systematically exclude smaller companies." Successful small firms like Cypress and IDT also claim that they are already ahead of Sematech technologically and thus would not benefit from it. S. Moran, "Sematech's Hefty Member

Fees May Bar Small Chip Makers," *San Jose Business Journal*, May 30, 1988; V. Rice, "Sematech: United We Stand?" *Electronic Business*, May 1, 1988.

57. Models might be drawn from Germany's Baden-Wurtemberg, where public research institutes, regional governments, and trade associations support networks of innovative small and medium-sized machinery producers. G. Herrigel, "Industrial Order and the Politics of Industrial Change: Mechanical Engineering," in P. Katzenstein, ed., *Toward a Third Republic* (Ithaca, NY: Cornell University Press, 1988).