new semiconductor startups also provided a managerial model for local entrepreneurs. Following the pattern pioneered by the semiconductor ventures, these entrepreneurs had little interest in building long-lasting social institutions. Rather their goal was to use their firms as vectors for personal enrichment and technological innovation. They wanted to bring their company public and sell shares to outside investors. Many entrepreneurs adopted the new forms of management-employee relations, which had been developed at Intel, at National, and at other semiconductor startups. They gave stock options to their professional employees in order to align their interests with those of entrepreneurs and venture capitalists. These managerial techniques became increasingly central to the Silicon Valley way of doing business. By the early and mid 1970s, the manufacturing cluster on the San Francisco Peninsula was profoundly different from the one Charles Litton, Bill Eitel, and Jack McCullough had helped build 30 years earlier. It had crystallized into a new type of industrial district—one centered around semiconductor electronics and characterized by the culture of entrepreneurship, heavy reliance on inexpensive Asian labor, and close ties with financial markets.[63]

Conclusion

"It seems remarkable to me," William Eitel reflected in 1962, "that on the San Francisco Peninsula, off the beaten paths of commerce, grew so many independent new industries, all now of national and international importance."[1] In the 1960s, the Peninsula was indeed much different from the region Eitel had known as a young radio amateur 40 years earlier. In the late 1920s, the Peninsula was mostly a rural region and home to a handful of radio firms. These firms had a cumulative workforce of a few hundred engineers and operators. Four decades later, the region had become the main center for electronic component manufacturing in the United States, employing 58,000 engineers, technicians, and operators. Local firms dominated both the domestic and foreign markets for advanced tubes and semiconductors and had become major suppliers to the Department of Defense as well as a wide range of commercial industries. From an economic backwater, the San Francisco Peninsula had, in less than 40 years, become a major technological and commercial center.

The manufacturing district grew by bringing together a variety of technological groups. Three partially overlapping technical communities emerged and expanded on the San Francisco Peninsula: radio amateurs, microwave engineers, and semiconductor technologists. Radio amateurs were indigenous to the Peninsula. Starting in the 1900s, and partly because of its strong maritime tradition, the Bay Area was one of the nation's largest centers for amateur radio. The other two technological groups converged around a nucleus of western-born scientists and engineers who had worked at East Coast firms during and after World War II and then moved back to California after the war. For example, the Varian group, which had worked at Sperry Gyroscope on Long Island during the war, organized a microwave tube firm on the Peninsula in 1948. Similarly, William Shockley, a Palo Alto native who had made his career at the Bell

Telephone Laboratories, set up a laboratory specializing in the development of silicon transistors in the area in the mid 1950s. These entrepreneurs attracted many other microwave and semiconductor technologists from other regions. In turn, many of these transplants established their own firms on the San Francisco Peninsula.

Radio amateurs, microwave engineers, and semiconductor technologists brought with them new skills and technologies. Each entrepreneurial group was also characterized by its own distinct culture, values, as well as style of work and organization. Radio amateurs recreated and improved upon the power tube technologies developed by large East Coast firms in the 1920s and the 1930s. These men also developed a subculture characterized by its camaraderie, a strong democratic ideology, and genuine appreciation of ingenuity and innovation. The other two groups, microwave engineers and semiconductor technologists, introduced to the Peninsula advanced component technologies they had helped develop at East Coast firms during the war and in the immediate postwar period. These groups also brought their own professional ideology and political ideals. The microwave and silicon communities both valued egalitarianism and viewed engineers as independent professionals. However, the microwave and semiconductor communities differed in other ways: a substantial number in the microwave group had socialist leanings and utopian ideals and longed for a society where the distinction between capital and labor would be abolished. In contrast, the semiconductor community was meritocratic and resolutely capitalistic.

These groups established new firms on the San Francisco Peninsula, which addressed the needs of the armed services and various commercial industries for advanced electronic components. Like their competitors on the East Coast, these firms benefited enormously from the growing demand for vacuum tubes and semiconductors. The military provided a large market for their products during both World War II and the Korean War. This demand continued through the arms race of the late 1950s and early 1960s. In the case of microwave tube firms, the Department of Defense financed R&D efforts and supported the construction of new facilities. But when the military cut back its component expenditures and radically altered its procurement policies in the early 1960s, the component firms in Silicon Valley had to reorient themselves toward the commercial markets. The microwave tube corporations diversified into scientific instrumentation and semiconductor manufacturing equipment. The semiconductor firms opened up large markets for silicon transistors and integrated circuits in the civilian sector.

Silicon Valley firms fared well under these changing conditions. They grew faster than their East Coast counterparts and often surpassed them in the late 1950s and the 1960s. Several factors explain the "success" of Silicon Valley as a manufacturing district. The entrepreneurial groups and their firms developed very unusual manufacturing and product engineering competencies. Silicon Valley's innovator-entrepreneurs recognized manufacturing process knowledge that was critical and they pursued, captured, and leveraged this knowledge over the whole period. For example, Charles Litton, William Eitel, and Jack McCullough devoted themselves to the *making* of vacuum tubes. They engineered innovative manufacturing techniques, which enabled them to produce tubes with a very high vacuum. Varian Associates devised new ways of making reflex and high-power klystrons. But it was the group at Fairchild Semiconductor that was the most innovative in manufacturing. It developed the planar process—arguably the most important innovation in twentieth-century technology. The planar process made possible the manufacture of integrated circuits. In the 1960s and the early 1970s, the Fairchild group and the engineers they trained developed many variants of this process. In addition, these men gained unequaled expertise in the mass production of silicon devices. They maintained their leading edge well into the 1970s.

These manufacturing capabilities made Silicon Valley. They enabled local firms to engineer and produce highly reliable electronic components with very high performance. Eitel-McCullough, Litton Industries, Varian Associates, Fairchild Semiconductor, Intel, and National Semiconductor produced some of the highest-quality vacuum tubes and semiconductors in the country. Significantly, the district's bias toward quality matched the evolution in the demand for electronic components. In the mid and late 1950s, the military shifted its procurement of electronic components toward highly reliable tubes and semiconductors. Likewise, the makers of computers and consumer electronics were seeking faster and more reliable microcircuits in the following decades. While local firms greatly benefited from this shift in markets, East Coast corporations, which emphasized cost and volume production, lost market share and were often forced to leave the component business.

Manufacturing expertise also enabled Silicon Valley firms to achieve high production yields—the main economic variable in the electronic component industries. For example, during the Korean War Litton Industries obtained yields of 95 percent on some advanced magnetrons. This contrasted with the competitors' yields, which were in the 5–30 percent range. Similarly, semiconductor corporations on the Peninsula had higher yields than most of their competitors for bipolar and MOS integrated circuits. These yields gave Silicon Valley firms a tremendous competitive advantage over their East Coast rivals. Better yields enabled local firms to obtain higher profits (which was important in industries where the general level of profitability was low) and to lower their prices in order to increase market share.

Complementing their manufacturing expertise, component firms on the Peninsula developed strong marketing and system engineering capabilities. Eitel-McCullough, Litton, Varian, Fairchild, and Fairchild's spinoffs acquired deep knowledge of their customers and of the design of electronic systems. They knew nearly as much about their clients' products as the clients themselves knew. Because of its origins in ham radio and its employment of radio amateurs, Eitel-McCullough had an excellent expertise in radio system engineering. The founders of Varian Associates were experts both in klystrons and radar systems. Similarly, in the early 1960s, Fairchild Semiconductor acquired a competency in electronic system design, by hiring engineers from the computer, instrumentation, and consumer electronics industries. In the late 1960s and early 1970s, Fairchild's spinoffs followed suit by learning about the many electronic products that could use integrated circuits. This systems expertise enabled the vacuum tube and semiconductor corporations in Silicon Valley to anticipate the needs of their customers and engineer devices that met their requirements.

Silicon Valley firms also learned how to create new markets for their products. Because they made tubes and semiconductors that were complex and difficult to use, they had to help their customers learn to design them into their own products. In some cases, they actually engineered new products for their customers. Eitel-McCullough is a case in point. To create a market for its power klystrons in the 1950s, Eitel-McCullough designed a tropospheric scatter communication transmitter and gave this design to Radio Engineering Laboratories at no cost. Radio Engineering Laboratories produced this transmitter under its own name and bought Eitel-McCullough's klystrons to power it. Varian Associates followed similar tactics by educating academic chemists about the new technology and science of NMR spectroscopy. These educational efforts enabled Varian to create users for its NMR spectrometers.

The "art" of market building was pushed to new highs by Fairchild Semiconductor and its spinoffs. Fairchild's engineers wrote numerous applications notes to explain to customers what they could do with the transistors and integrated circuits. They also engineered new products such as transistorized television monitors around the firm's components and promoted these designs to their customers. Many Fairchild's designs were later put into production by consumer electronics firms such as Zenith and General Electric. In the late 1960s, National Semiconductor went one step further. It deployed field applications engineers who became actively involved in the engineering of their customers' products. Some field applications engineers went as far as directing the product engineering teams at user firms. These marketing and system engineering capabilities enabled Silicon Valley firms to open up new markets for their products, especially in the civilian sector, and to grow enormously in the late 1960s and the first half of the 1970s.

As these markets grew, the groups that built the power-grid tube, microwave tube, and semiconductor industries on the San Francisco Peninsula acquired a unique know-how in creating, financing, and managing startups. At these startups, Silicon Valley entrepreneurs pioneered new funding mechanisms and shaped novel management-employee relations. Charles Litton and the Varian brothers developed an uncanny ability to use military contracts as a means to finance the growth of their firms. The entrepreneurs and financiers who formed Fairchild Semiconductor went on to establish the venture capital industry on the San Francisco Peninsula.

Innovator-entrepreneurs in Silicon Valley also devised new ways of relating with employees. They were under the constant threat of unionization and they needed to secure the cooperation of a skilled workforce in order to build and control complex manufacturing processes. As a result, Silicon Valley firms developed a corporatist approach to management. They gave substantial autonomy to their engineering staffs and often organized engineering work around teams. They sought to involve their professional employees in the decision-making process. In addition, they developed unusual financial incentives for their work force: profit-sharing programs, stock ownership, and stock option plans.

Within this corporatist framework, one can distinguish three different approaches. Eitel-McCullough, Litton Industries, and many microwave tube firms adopted a participatory and paternalistic management style that emphasized profit sharing and generous employee benefits. Varian Associates had a socialist streak, developing a communal organizational and ownership structure. In contrast, Fairchild Semiconductor and most semiconductor firms pioneered an entrepreneurial form of corporatism organized around stock options. Starting in the early 1960s, Fairchild and its spinoffs granted stock options to engineers and middle managers. These options, which offered the right to buy stock at a predetermined price at a future date, had been reserved until then to upper management at East Coast firms. Instead, managers on the Peninsula offered these options to engineers and middle managers as well. As a result, employees were able to benefit from an increase in the valuation of their companies' stock.

Because of these new financial incentives and organizational forms, electronics firms on the Peninsula attracted some of the best design, processing, and manufacturing engineers in the United States from the 1940s to the 1970s. These innovations also permitted Silicon Valley firms to deploy their engineering workforce efficiently and to improve employee productivity. Flat organizational structures, profit sharing, and stock option programs gave them a substantial competitive advantage over their more traditional Eastern counterparts.

The constant circulation of design, production, and management skills within the district also explains the "success" of individual corporations and the manufacturing cluster as a whole. Manufacturing processes, design methodologies, and managerial techniques moved quickly from firm to firm and from industry to industry. Tube and semiconductor firms developed close alliances with their suppliers of manufacturing equipment. For instance, Eitel-McCullough used Litton Engineering's glass lathes and developed new assembly techniques. Skills and techniques flowed within industries as engineers moved from one corporation to the next. For example, many semiconductor entrepreneurs appropriated the manufacturing processes they had mastered (and often helped develop) at their previous employers and built new businesses on the basis of this know-how. Skills, practices, and techniques also moved across industries. Semiconductor manufacturers relied heavily on the competencies nurtured by the vacuum tube corporations. They hired technicians and process engineers from the vacuum tube firms. They borrowed new managerial techniques from Varian Associates and used them (with some modifications) to relate to their own employees.

But what sustained the circulation of practices and techniques throughout Silicon Valley? This circulation was partially predicated on the culture of cooperation that electronics hobbyists developed on the San Francisco Peninsula. Radio amateurs valued collaboration and the sharing of information—both in technology and business. Litton, a radio ham and microwave engineer, freely shared his knowledge of vacuum techniques and tube production methods. He also helped other entre-

preneurs start electronics firms in the area. The flow of innovations was further facilitated by a sense of regional pride and the perception of common interests. The tube and semiconductor corporations on the Peninsula were late entrants in industries pioneered by large East Coast firms. Western pride and the imperative of surviving in industries dominated by the East led early Peninsula firms to band together against their larger competitors. Also critical were the dense networks of personal relationships that emerged in the region. In the early 1960s, Fairchild Semiconductor employed a large fraction of all semiconductor engineers on the San Francisco Peninsula. At Fairchild, these men built friendships and professional ties. After leaving the company, they kept in touch, helped each other, and traded information across firm boundaries. Stanford University also reinforced the regional circulation of skills by appropriating process and design technologies from Litton Engineering, Litton Industries, and Shockley Semiconductor. The university later codified and systematized this industrial knowledge and imparted it to engineering students, who in turn carried it to other corporations in Silicon Valley.

These flows of manufacturing techniques and managerial skills across firms and industries were critical to the rise of Silicon Valley. They enabled the rapid adoption of "best practices" across the district. They also led to the formation of region-specific bodies of knowledge that were crucial for the commercial success of local firms. Because they raided each other's employees and benefited from informal contacts among their engineers, MOS startups on the Peninsula developed a repertoire of process "tricks" which were known only in the area. These tricks enabled MOS companies to introduce new products rapidly to the market and to obtain good manufacturing yields. In contrast, MOS firms located outside of Northern California were not plugged into these networks and did not benefit from this shared knowledge. This put them at a distinct disadvantage since the MOS processes were very difficult to master and control.

The Peninsula's electronic component manufacturing complex provided the foundation for much of Silicon Valley's growth in the 1970s. Although local tube and silicon corporations retained and advanced their preeminent position in component manufacturing in the United States, much of the growth during this period came from the system sector. The late 1960s and the 1970s saw the emergence of new "industries" making calculators, computers, electronic watches, and video games on the Peninsula. Many semiconductor firms and entrepreneurial groups entered the digital watch and calculator businesses. There was a similar entrepreneurial flourish around video games—with the formation of firms such as Atari. Other groups made mainframes (Tenet) and fail-safe computers (Tandem). Hewlett-Packard and Varian Associates entered the minicomputer business. In the late 1970s, a new industry—personal computers—emerged with the formation of Apple Computer, Osborne Computer, and other startups.

Each of these industries made use of capital and technical and managerial competencies acquired by the tube and semiconductor communities. The electronic component industries were a source of funds for the new system ventures as fortunes made in components were reinvested in system businesses. For example, Robert Noyce and Gordon Moore financed computer and medical instrumentation startups in the 1970s. Component firms were a major source of managerial talent for the system sector and they supplied engineers knowledgeable about component and system design. Fairchild, Intel, and National supplied integrated circuits to local computer, instrumentation, and consumer electronics firms. These components made calculators, digital watches, and personal computers possible.

Apple Computer was emblematic of the deep ties that emerged between the system and component industries in Silicon Valley. Apple Computer was started by two young electronics hobbyists, Steve Wozniak and Steve Jobs, who were sophisticated users of microprocessors and other integrated circuits. Early on, they hooked up with the social networks in the semiconductor industry. In the first months of Apple's formation, Jobs approached Donald Valentine, a venture capitalist who had formerly directed sales and marketing at Fairchild and National Semiconductor, and asked him to invest in Apple. While Valentine declined at first to finance the startup, he advised Jobs to contact Mike Markkula, one of his former associates at Fairchild. Markkula, who had made a small fortune in the semiconductor business, had recently retired from Intel.[2]

Markkula understood the system possibilities opened up by the microprocessor and was quick to grasp the potential of Apple's first machine. Betting that Apple could become a large and successful firm, Markkula joined the company in 1977. He invested $92,000 of his own money in Apple Computer and convinced Jobs and Wozniak that they needed professional managers. To run Apple on a day-to-day basis, Markkula hired Michael Scott, a former manager at Fairchild and National. Markkula also raised the capital needed to finance Apple's growth. Among the investors were Valentine and Arthur Rock, the venture capitalist who had financed

the formation of Intel and Intersil. Valentine and Rock joined Apple's board of directors. With this influx of managerial expertise, Apple rapidly adopted the "best practices" of Silicon Valley's semiconductor industry. The firm emphasized innovation, the development of quality products, and rapid sales growth. It also attracted and retained skilled engineers and managers by granting them attractive stock option packages (Gupta 2000).

The goal of Apple's managers was similar to that of most semiconductor entrepreneurs. They wanted to take the company public within 5 years and make a killing in the stock market. The design skills of Wozniak and other hobbyists in Apple's technical staff made this objective possible. In late 1976 and early 1977, Wozniak developed a successor machine to the Apple I. The revolutionary Apple II attracted a strong following among software programmers, who wrote application programs for the Apple II such as VisiCalc, a spreadsheet program. These programs "sold" the Apple II to the American public. As a result, the firm grew enormously. By 1980, Apple was the leading firm in the personal computer industry. It had a user base of 120,000 computers and was one of the 500 largest corporations in the United States. The company's rapid sales growth enabled its management to take Apple public and reap enormous capital gains. In turn, Apple's stellar success fueled the expansion of the computer, software, and disk drive industries on the San Francisco Peninsula, once again repeating the pattern of Silicon Valley. More than anything else, the making of Silicon Valley was the repetition of this pattern—as one generation of engineers mastered the mystery of design and manufacturing sophisticated electronics, so the next generation borrowed and learned from their predecessors. Manufacturing districts grow and thrive only so long as they remain communities of learning, practice, and collaboration.