Silicon Valley and Route 128 Won't Save Us

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> There are a variety of things [high] technology industry depends upon that really can't be done well by small companies. Some of the major systems problems have such a broad scope that they require a fairly large group of mixed technical talents. . . . Many technological things have to be undertaken over a long time. After some of the initial work is done it can be relatively efficient to move to fruition through a start-up. But increasingly, it takes big investment and long times to do the basic technology.
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> —Gordon Moore, Intel[1]

For many, if not for most, Americans, Silicon Valley and Route 128 stand out as symbols of economic and technological success. Their image of freewheeling, high-technology entrepreneurship and quick-shooting venture capital fits in nicely with our free enterprise ideology. These areas are typically held out as models for the rest of the American economy—in striking contrast to the failure of our large corporations and the economic devastation faced in older industrial regions.[2]

The reasons for the rapid growth of Silicon Valley and Route 128 are widely misunderstood. In recent years, two theories have received great attention for their ability to explain those model of high-technology organization and for their faith that this model of can keep the U.S. ahead of its major competitors.

The first is the view that small firms are somehow better suited to new high-technology fields than are big ones. This view is most boldly formulated in George Gilder's "law of the microcosm," which suggests that small entre-

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preneurial firms have a natural advantage in the new "micro" technologies of the high-tech age.[3] He contrasts this with the old-scale economies that operated so well for the production of large things like automobiles and slabs of steel. In Gilder's words: "Rather than pushing decisions up through the hierarchy, microelectronics pulls them remorselessly down to the individual. This is the secret of the new American challenge in the global economy and with the microprocessor related chip technologies, the computing industry has replaced its previous economics of scale with new economies of microscale."[4]

The second theory suggests that networks or communities of small firms are a more effective form of economic and technological organization than are large integrated companies. The main proponents of this theory, Michael Piore and Charles Sabel, argue that "flexibly specialized" networks of small firms are characterized by close relationships, shared trust, and intense cooperation in the development and production of new products.[5] They base their theory on case studies of the high-fashion clothing and footwear industrial districts of northern Italy, an area they refer to as the "third Italy." According to this theory, Silicon Valley and Route 128 are high-technology versions of "cooperative" industrial districts where firms cooperate with one another in the development of new products making it possible for them to remain small but still be globally competitive. According to a recent account by a proponent of flexible specialization theory: "Silicon Valley firms describe their relations with suppliers in the language of personal rather than business relationships. They talk of building trust, making long-term commitments, 'holding hands with,' and even 'getting into bed with' suppliers."[6]

These theories offer an easy "things will take care of themselves" solution to the high-technology challenge—in an imaginary high-technology world in which "microscale," "flexibility," "trust," and "cooperation" keep the U.S. economy ahead of the pack. But before we accept these answers, we must examine the evidence for such claims.

A Hobbesian World

The unfortunate reality of Silicon Valley and Route 128 is one of severe, at times devastating competition that drastically limits the ability of small entrepreneurial firms to cooperate with one another and to generate follow-through on cutting-edge technological innovations. Rather than a harmony of interests, the reality is one of each protecting his own—a trait clearly reflected in the recent rash of lawsuits charging companies with stealing employees or copying technology. Cypress Semiconductor, for example, currently faces at least 20 intellectual property lawsuits. Larger firms like DEC and Intel have developed in-house staffs of ten or more lawyers to deal with intellectual property litigation.

The Hobbesian side of American high technology is especially evident in the highly competitive relationships between companies. In the cutthroat environment of Silicon Valley and Route 128, passing problems on to others is considered smart business rather than a violation of trust. Each firm, its venture capitalists, and stockholding employees try desperately to increase their profits and their success at the expense of both their competitors and their "collaborators," for example, their suppliers. While a few large companies like DEC, Hewlett-Packard, and Apple have tried to develop closer, longer-term relations with their suppliers, most have not. In the pressure cooker environment of Silicon Valley and Route 128, there is little burden sharing between companies; contracts are broken and suppliers let go when a better deal can be had elsewhere. A recent study of the state of the U.S. semiconductor industry is clear on this point: "The U.S. semiconductor producers and their equipment and material suppliers are disaggregated and have little tradition of cooperation and mutual support."[7]

Most companies try to drive prices down by pitting one supplier against another. Not surprisingly, suppliers respond to these conditions by competing mainly on price, delivering cheaper products that are of lower quality and are less reliable. And if a shortage arises, suppliers have every incentive to drive up prices mercilessly. According to *Electronic Business:* "Electronics manufacturers, like most others, have traditionally used a common approach when choosing goods and services suppliers: give us your cheapest prices and we'll give you our business."[8]

Stock-piling and hoarding are commonplace in the high-stakes environment of Silicon Valley and Route 128, where companies try to outguess the market and where suppliers seem to rise and decline overnight. Apple Computer, a company hailed as a pioneer in close supplier relations, lost tens of millions of dollars in 1989 when it stockpiled dynamic random access memory (DRAM) semiconductor chips in anticipation of shortages and escalating prices, as recounted in a recent report: "After hoarding millions of dollars worth of expensive DRAMs, when the market was tight, chip supplies loosened and the market fell. Alas, the personal computer maker was stuck with a stockpile of overpriced memories—a costly purchasing blunder. . . . Apple's dilemma is not unique. A single misguided purchasing decision can save or lose millions of dollars for a company."[9] This inefficient strategy of stockpiling also injects incorrect information on demand into the market.

Most high-technology companies of Silicon Valley and Route 128 make little effort to develop tight permanent relationships with even their most valued suppliers. The "arm's length" relationship is the rule. Companies may register a complaint when deliveries are late, but that is the extent of it. They generally do not foster any communication beyond the actual purchase agreement. Suppliers may be asked their "opinion," but they are rarely seriously consulted on design options. In fact, most current attempts to reform supplier relations are more hype than reality. DEC's much-heralded "Key Supplier" program extends to just 20 of the company's 2,000 plus suppliers. According to Ron Payne, vice-president for corporate purchasing at DEC, the company is "moving away from a straight competitive bid environment and toward a longer term relationship" for this select group of key suppliers.[10] But for the rest, competitive bids and arm's-length relationships are the order of the day. Hewlett-Packard's new supplier program depends mainly on punishing suppliers who deliver defective products or make late deliveries. For example, when a defect is identified, all Hewlett-Packard divisions are placed on "quality alert" and prohibited from buying from the supplier until the defect is corrected and a "correction notice" is issued.[11] These so-called reforms stand in sharp contrast to the long-term, mutually supportive supplier relations found in Japan where large hub firms work closely with their suppliers to help them solve quality or delivery problems.

What's more, Silicon Valley and Route 128 firms often go outside their region to find low-cost sources of supply. A recent study based on detailed interviews with 40 high-technology companies in Silicon Valley indicates that more than half the companies have relationships with equipment suppliers located outside the region and that these relationships are mainly commercial or "arm's length" in nature. Furthermore, roughly two thirds of the principal components or inputs used in the development of new products come from suppliers outside the region. Local suppliers mainly provide "nontechnology" products, such as cabinets, castings, power supplies, raw materials, basic chemicals, and office supplies and highly standardized high-tech components, such as a computer disk. The study concludes that: "the region's integration within a broader global milieu is increasing as local linkages . . . decline in importance."[12]

Silicon Valley and Route 128 firms contract out a large and growing share of manufacturing to specialized "contract manufacturers" chosen mainly on the basis of price (as opposed to proximity or quality). Contract manufacturers frequently locate their plants in the Sunbelt and Third World where labor costs are low. A common pattern is to have a main sales office and a small plant in Silicon Valley or Route 128 to serve special customer demands and larger, high-volume plants in low-wage Sunbelt states, Asia, and Mexico. Flextronics, a leading contract manufacturer for Silicon Valley semiconductor firms, has plants in the Sunbelt, New England, Southern California, and Hong Kong, as well as Silicon Valley. SCI Systems, another important contract manufacturer, is headquartered in Alabama to take advantage of low wages. A large and growing number of high-tech companies have manufacturing done by foreign companies such as the Taiwan Semiconductor Manufacturing Company who pay extremely low Third

World wages.[13] Contract manufacturers offer a cheap outlet for production but seldom if ever perform the role of collaborative partners in the development or improvement of products.

Much attention has been focused on the cooperative relationship between Sun Microsystems, a cutting-edge workstation manufacturer, and Cypress Semiconductor, a leading custom chip company that produces tailor-made chips for Sun.[14] But the close relationship between Sun and Cypress is an exception engineered as an "experiment" by the venture capital fund Kleiner Perkins, which backs both companies. According to John Doerr of Kleiner Perkins, the venture fund has sought to re-create elements of Japan's industrial network structure among the entrepreneurial companies in which it has invested. Kleiner Perkins wants to play the dual role of central financial institution and anchor institution for a galaxy of linked corporations, a role that in some ways resembles that of the bank in the Japanese keiretsu system.[15]

Sun has experienced problems in its attempts to fashion a model "solar system" of vendors and suppliers. According to a recent report, many current members of Sun's solar system are constantly worried by their dependency on their "Sun," which could at any time move to cut them out.[16] Furthermore, Sun was unable to find a suitable American supplier for the original reduced instruction set chip (RISC) that forms the heart of its pioneering workstation. After a series of failed negotiations with American chip makers, Sun turned to the Japanese electronic giant Fujitsu for this product.[17] Cypress came into the picture later. In a Fujitsu advertisement in *Business Week,* Sun president Scott McNealy is quoted as saying: "This is our longest steady corporate relationship. Fujitsu has been a key partner of ours. . . . Fujitsu was one of the first companies to take a chance on Sun. They treated us like a big company when we were barely out of the start-up phase. They have supplied us everything from DRAMs to disk drives."[18]

The Sun-Fujitsu relationship highlights another drawback to the Silicon Valley/Route 128 model of the high-technology organization: so many American high-technology companies buy their products from Japanese multinationals rather than from local "partners." The director of purchasing for a U.S. high-technology company provides some perspective: "The Japanese concept of just-in-time is to ring your plant with suppliers in the shadow of your building. That concept is fine but it is in basic conflict with the fact that in the U.S. many of our suppliers are in the Pacific Rim."[19] CEOs and purchasing directors of U.S. start-ups provide countless stories of how they are unable to get their domestic suppliers to provide high-quality components and are forced to turn to Japanese competitors instead. Robert Shillman, CEO of Cognex, a Route 128 company, indicates that his company was willing to pay a 20 percent premium to a U.S. supplier, but still ended up buying from a Japanese company because no U.S. firm could match the quality.[20] Jerry Crowley, Chairman of Gazelle Microelectronics, a Silicon Valley manufacturer of gallium arsenide chips, says that Kyocera's San Diego plant was one of the first to do business with his small 11-person company, which many U.S. companies considered too small to do business with.[21] Don McCraine, CEO of SEEQ Technology, says his company has no choice but to turn to a Japanese supplier for semiconductor packages (the finish work on semiconductor) because "there are no U.S. manufacturers left capable of making semiconductor packages . . . . Now if you buy a [semiconductor] package, you buy a Kyocera package. Every missile system made in the United States may have a U.S.-made chip in it, but it will be a Kyocera package."[22]

To serve this growing market, increasing numbers of Japanese firms are opening state-of-the-art semiconductor design centers in Silicon Valley and the Route 128 area. These firms work closely with their American customers to come up with tailor-made designs. The custom designs are then dispatched via electronic mail to state-of-the-art Japanese manufacturing facilities that produce the actual chips, which are then shipped back to the U.S. by air. These Japanese firms are now going the next step by building new semiconductor manufacturing facilities in the U.S.

Leading U.S. semiconductor companies are becoming overwhelmingly dependent for their production equipment upon Japanese companies, such as Canon, TEC, and Nikon. LSI Logic, for example, gets more than 60 percent of its production equipment from Japan because domestic manufacturers are unable to deliver reliable high-quality products.[23] Certainly, if relationships were harmonious and highly interactive, Silicon Valley's semiconductor companies would not have abandoned their fellow U.S. suppliers of production equipment. Indeed, a history of strained, adversarial relations between chip companies and semiconductor equipment manufacturers underscores the decline of the U.S. semiconductor production equipment industry.[24] Harvey Jones—president of Synopsis, past president of Daisy Systems, and former venture capitalist—sums it succinctly: "You cannot build a high-technology economy by flipping out start-ups and leave the rest of it to the Japanese."[25]

On yet another dimension, American producers of advanced semiconductor design automation equipment and high-tech instruments are finding that large Japanese corporations comprise a large and rapidly growing share of the market for their cutting-edge products. Cognex not only depends on Japanese suppliers, but sells between 20 and 40 percent of its machine vision systems in Japan.[26] MRS Corporation, a leading manufacturer of x-ray lithography equipment used in advanced "active-matrix" laptop computer screens, currently sells 80 to 90 percent of its systems in Japan and the rest in Europe; the company has been unable to sell any in the U.S.[27] Executives of leading Silicon Valley design automation firms like Silicon Compiler Systems, Cirrus Logic, Synopsis, and SDA (now Cadence) and high-tech equipment instrument producer KLA Instruments told us that

Japanese corporations are buying more and more of their products.[28] Even advanced semiconductor manufacturers like Brooktree and Altera are doing more business in Japan; Altera estimates that by 1991 more than 20 percent of its sales of programmable logic chips will come from Japan.[29] According to *Electronic Business,* foreign sales by the top 200 U.S. high technology electronics companies rose by 42 percent in 1988, while domestic sales increased by a mere 2.4 percent.[30] The point of all this is basic: While Silicon Valley and Route 128 firms may innovate locally, the markets for their high-technology products are shaped by strong market forces that are increasingly global in scope and may in fact ultimately contribute to the demise of U.S. high technology itself.

Start-up Mania

The Hobbesian side of the U.S. model of high-technology organizations is further reflected in the proliferation of "me-too startups," or copycat companies, that occupy nearly all areas of the high-technology industry. Me-too start-ups are linked to "technology fads," the rapid rise of hot new technologies. In the high-stakes world of American high technology, the emergence of a new technology produces a rush of clones as everyone tries to cash in on the latest technology fad. Donald Valentine explains: "The sopping up of resources by multiple startups . . . is detracting from the competitiveness of U.S. industry. It used to be that the only competition we faced was from larger, well-established companies that didn't recognize a market niche or an opportunity. It took most of us to finance one company into business, two at the most. Now . . . each [venture capital] group feels it has to have one of every kind of an investment.[31]

The phenomenon of me-too start-ups is related to the tremendous expansion of the venture capital pool, which increases both the opportunity and the pressure to produce new start-ups. John Wilson uses the term "feeding frenzy" to convey the reckless abandon in financing clone start-ups.[32] An excellent example of such over-investment is the personal computer disk drive industry:

> From 1977 to 1984, venture capital firms invested almost $400 million in 43 different manufacturers of Winchester disk drives . . . including 21 startup or early stage investments . . . During the middle part of 1983, the capital markets assigned a value in excess of $5 billion to 12 publicly traded, venture capital backed hard disk drive manufacturers. . . . However, by 1984, the value assigned to those same 12 manufacturers hade decided from a high of $5.4 billion to only $1.5 billion. . . . when viewed in isolation each [funding] decision seems to make sense. When taken together, however, they are a prescription for disaster.[33]

The result was a shake-out of companies with large financial losses and massive layoffs. A second domestic shake-out that occurred in 1989 left only four U.S. drive makers—Conner Peripherals, Maxtor Corporation, Quantum Corporation, and Seagate Technology—to meet the growing challenge of large Japanese companies who are rapidly increasing their share of the hard disk market. Quantum has in fact established a partnership with Matsushita to manufacture low-end disk drives. Conditions have gotten so bad for U.S. disk drive producers that George Scalise of Maxtor has called for the establishment of a federally supported consortium of U.S. disk drive companies to overcome the damaging effects of domestic competition and beat back the Japanese challenge.[34]

In biotechnology, similarly, the proliferation of start-ups has been great, with venture capital funds backing over two hundred new companies. Numerous start-ups scrambled to be the first to market in nearly every product category.[35] This is a new development in the pharmaceutical industry, which has a strong tradition of patenting and "first mover" advantages. While the biotechnology industry has thus far avoided a shake-out (mainly by opting for mergers among small companies), me-too-start-ups have spread the narrow base of biotechnology talent across a large number of companies that caused considerable redundancy in R&D. This has also forced a host of start-ups into joint ventures with domestic and foreign competitors.

Me-too-start-ups, in dividing market share and talent among companies, weaken many in ways that can threaten the development of entire industries. The proliferation of copycat companies in narrow business areas makes it difficult to establish the continuity it takes to follow through and often leads to serious misallocations of resources, business failures, and destabilizing shake-outs. Thus, clone companies may appear rational from the perspective of each entrepreneurial group and venture investor, but they often end up hurting the high-technology industry as a whole.

The Hobbesian realities of Silicon Valley and Route 128 fly in the face of academic theorists who would like to explain their technological dynamism and economic performance in terms of a theory of economic cooperation based on the high-fashion clothing and footwear industries of northern Italy. Perhaps the most insightful perspective on this issue was provided in an interview we conducted with Luigi Mercurio, an Italian high technologist and former Olivetti executive who now lives and works in Silicon Valley as CEO of David Systems.[36] Mercurio sees little if any similarity between Silicon Valley and Italy's much-heralded industrial districts. For him, Silicon Valley epitomizes a free-wheeling, entrepreneurial economy where technological innovation is motivated by the potential to profit and accumulate great wealth. The "third Italy" exemplifies an "old-world economy" where generations of family ties exert powerful influence over the local economy. In Silicon Valley, the rule of profit dominates; the firm itself has become a commodity to be bought and sold to the highest bidder. In the "third Italy," decades' old social ties and community relationships place strict limits on economic behavior and the "family firm" remains a source of livelihood and support for many generations. One does not need a theory of cooperation and trust to explain the innovativeness and economic dynamism of Silicon Valley or Route 128, when a simple understanding of the super-profits that come from breakthrough innovation will do. Although a cooperative community of high-technology firms and their suppliers is certainly a desirable ideal, the reality is a competitive war of all against all in which the outcome is tremendous profit for some and exhaustion for many others.

Industrial Fragmentation

All of this has contributed to a growing problem of industrial fragmentation, which comprises two elements, one horizontal and one vertical. These can be illustrated by a tree metaphor. A firm's base product can be considered the trunk. Successful R&D not only strengthens the trunk but also leads to the development of new "branch" from the trunk, that is, new products in related areas. The branches allow the company to diversify and become stronger and more stable. Horizontal fragmentation transforms these branches into self-standing companies. The parent company is left with its trunk and very little possibility of growth through branching. Vertical fragmentation splits the tree into separate sections running from the roots to the leaves. Instead of working together as a single organism, the tree is split into several independent entities, that is, roots, branches, and leaves. Each of these segments then must operate in its own best interest to ensure its own profitability.

The semiconductor industry is the most obvious case of horizontal fragmentation. The semiconductor industry is split into five segments: merchant producers, captive producers, integrated circuit producers, design specialists, and subcontract manufacturers.[37] According to one recent report: "America's semiconductor makers are mostly specialist, independent companies; Japan's are high volume subsidiaries of giants. In the past five years, America's small firms have lost their dominance of the world memory chip market to big Japanese rivals. They now fear they will lose the rest of the business too."[38]

Horizontal fragmentation leaves most semiconductor firms entirely dependent upon a single core product. A narrow product base makes it impossible to cross-subsidize products, leaving many firms vulnerable to major technological changes, price swings, and industry downturns. A slump in personal computer or workstation sales, for example, could wipe out a whole host of specialized semiconductor producers and even cause significant financial problems for large producers. And when an international price war breaks out, such highly specialized companies are in trouble almost immediately. High degrees of industrial fragmentation have weakened the U.S. semiconductor industry, leaving it increasingly unable to respond to foreign competition.

The computer industry is divided into at least ten separate segments, with only a handful of companies like IBM, DEC, and Hewlett-Packard important players in more than one. The mainframe segment remains dominated by IBM, and to a lesser extent by the remaining members of the

BUNCH [i.e., Burroughs, Univac (now Unisys), NCR, Control Data, and Honeywell (now out of the business); two Japanese players, Fujitsu and Hitachi, have also joined this sector], as well as "plug-compatible" manufacturers, like Amdahl.[39] DEC, Data General, IBM, and HP are the major producers of minicomputers.[40] Fault-tolerant computers are made by Tandem, Stratus, and Tolerant Systems. Sun Microsystems and Hewlett-Packard are the largest producers of engineering workstations.[41] Apple, IBM, and Compaq dominate the personal computer segment.[42] Laptops are made by Compaq, Grid Systems, and Zenith, and smaller notebook computers are being made by new start-ups, including Agis, Go Corporation, Information Appliance, and Poqet Computer, which is 38 percent owned by Fujitsu.[43]

Within this industry, the supercomputer segment has undergone and extreme horizontal division. It is populated today by more than twenty-five companies, which compete in a variety of areas.[44] The company most usually associated with supercomputing is Cray Research.[45] Recently, Cray has been challenged by Supercomputer Systems, a company founded by a former Cray computer scientist, Steven Chen, and forty-five defecting Cray employees.[46] Seymour Cray recently spun off another new company to make next generation supercomputers. The supercomputer segment has divided into a series of minisegments. A new minisupercomputer segment has emerged and is dominated by two new start-ups, Convex and Alliant, but recent entrants include Elxsi, Floating Point Systems, Multiflow, Saxpy, SCS, Sky, Gould, and Cydrome.[47] Parallel processing computers that use more than one processor are being made by new entrepreneurial companies like Sequent Computer Systems, Encore Computer, Thinking Machines, Flexible Computer, Floating Point Systems, NCube, and BBN Advanced Computers.[48] Manufacturers of desktop supers include Ardent Computer and Stellar, which merged in 1989 under the aegis of Kubota.[49] The tragedy in supercomputers is that these companies do not communicate and share information either across or within segments.

Obviously even IBM's formidable presence has not prevented massive waves of new entrants and increasing fragmentation in the computer industry. According to computer industry expert, Kenneth Flamm: "IBM sometimes lagged in the introduction of new technology into its product line: time sharing systems, the use of integrated circuits, large-scale supercomputers, small-scale minicomputers and microcomputers, and software making use of artificial intelligence are areas where IBM trailed more aggressive competition." For a time IBM was able to absorb these new developments and cope with, indeed capitalize upon, increasing fragmentation. But even "Big Blue" has come under increasing pressure both from start-up companies and from Japanese competitors in recent years laying off 10,000 people in 1989 and reporting a record $3.8 billion dollar drop in net income.[51]

American high technology suffers from an extreme form of vertical as well as horizontal fragmentation. Vertical fragmentation means that various functions of the firms, ranging from R&D to manufacturing, are parceled out into independent firms, where each aspect of the production chain is the province of a separate group of specialized companies.

The production of customized chips is a case study in vertical fragmentation. Custom chips (application-specific integrated circuits, or ASICs) are designed by specialized design firms, produced by independently owned foundries, and assembled by still another group of companies. The measurement, test devices, and other equipment used in the production process are made by yet other firms. In fact, only a handful of the recent semiconductor start-ups, such as LSI Logic and VSLI Technology, are integrated producers with complete design and manufacturing capabilities. Others such as Brooktree, Cirrus Logic, Maxim Integrated Products, S-MOS Systems, and Xilinix are "fabless" companies that have no manufacturing capability of fabrication plant and are entirely dependent upon outside manufacturers[52] Gorden Bell explains that the future of the U.S. semiconductor industry may be a "completely segmented industry in which the user, designer,... design center, and foundry are all separate.[53]

For some, like George Gilder and T.J. Rogers of Cypress Semiconductors, this new configuration is heralded as evidence of the flexibility and renewed competitiveness of the U.S. semiconductor industry.[54] But their optimistic spirits are dampened by the rise of large Japanese corporations who have become the main players in the low end of the customized chip business and who are squeezing the profit margins of LSI Logic and VSLI Technology, the most important U.S. producers of custom chips. An increasingly uncompetitive brand of overspecialization, not flexible specialization, is the distinctive feature of the U.S. semiconductor industry.

Vertical fragmentation also exists between industries. Consider the fault line between the semiconductor and computer industries. Only a handful of our largest computer companies, including IBM, DEC, and Hewlett-Packard, make the chips that go into their products; the others depend on outside merchant suppliers. In fact, IBM is the only major U.S. computer manufacturer that remains a major force in the development of new chips. According to Dataquest, IBM produced $1.8 billion of the $2.9 billion in semiconductors it consumed in 1986, purchasing the rest from outside suppliers.[55]

When Intel recently moved to vertically integrate by producing personal computers and computer workstations based on its own microprocessors, it sent shock waves through the American high-technology community, essentially calling into question the long-held division of labor between semiconductor producers and the computer systems makers they supply. Intel's move provoked an outcry from a number of the company's leading customers in the computer industry who see it encroaching upon their business and has even caused some to actively search out new suppliers. Compaq Computer, one of Intel's most important customers, has retaliated by providing venture funding for NexGen Microsystems, a company that produces clones of the Intel microprocessors used in its computers.[56]

This example illustrates a basic point. The highly fragmented structure of US. microelectronics has created patterns and rules of behavior that make it extremely difficult for companies to integrate. Companies like Intel that try to integrate or otherwise break away from the existing structure run the risk of alienating their customer and/or supplier base and may seriously jeopardize their own financial condition. While U.S. semiconductor and computer firms are engaged in this frantic jockeying for position, large, integrated Japanese corporations continue to make greater and greater inroads in virtually every microelectronic market from mass-produced semiconductors to custom chips and from laptops and personal computers to high-end supercomputers.

Taken together, horizontal and vertical fragmentation produce a pattern of highly fragmented industrial development that is the opposite of the traditional pattern of vertical integration, whereby large numbers of entrepreneurial firms eventually give way to large, integrated enterprises.[57] This fragmentation of American high technology did not just happen; it was the result of conscious historical choices. The choices and success of the founding fathers of American high technology created a set of institutions that supported entrepreneurial high technology and made fragmentation appear "natural." Fairchild and Intel founder Robert Noyce explains the historic choice made in the American microelectronics industry and, by extension, in American high technology: "We are going to less and less vertical integration. . . . All electronics firms do not feel that they must make their own semiconductor devices; nor do they feel they must grow single crystals, make their own masks, build their own furnaces or test equipment."[58]

Fragmentation can damage entire high technology complexes, which tend to specialize in a narrow band of high-technology products. The dramatic growth of Route 128 during the late 1970s and early 1980s was driven by the increasing demand for minicomputers, dedicated word processors, and office automation products manufactured by DEC, Data General, Wang Laboratories, Prime Computer, and other Route 128 companies. However, the shift to "distributed" personal computers that began in the mid-1980s undermined the market base of the manufacturers of these minicomputer and dedicated office systems and helped create a regional recession in 1989.[59]

The fragmentation and splintering of our high-technology capabilities makes it ever more difficult to build stable companies and industries that can compete over the long haul. Even our strongest, most innovative companies are finding it difficult to grow and prosper in such a highly fragmented environment. The extreme segmentation of the high-technology production process drastically inhibits technological follow-though and hinders American industry's ability to meet the challenge of emerging global competition.

Innovation Dilemmas

The combination of small size and industrial fragmentation makes it difficult for American high-technology firms to combine one or more technologies into new hybrid innovations or to generate systems technologies. "Mechatronics," the combination of mechanical and computer technologies, is a good example of a hybrid technology.[60] Mechatronic products include consumer goods like watches, cameras, and home appliances and industrial goods like industrial robots and machine tools. Systems technologies come from the combination of a variety of technologies in a workable system.[61] Television, telephones, and electrical transmission are good examples of systems technologies. For television to be successfully commercialized, a wide range of products such as television tubes, cameras, receivers, and transmission equipment had to be combined into a workable system.

Hybrid innovations and systems technologies can be of even greater economic importance than radical new breakthrough innovations. The application of mechatronics by Japanese firms to wristwatches, for example, revolutionized the watch market, opening up a huge new market in inexpensive and reliable quartz watches. According to recent reports, large Japanese companies dominate many important hybrid fields, including "mechatronics" and "optoelectronics," the combination of computer and video technologies.[62] Japan's recent ascent in high-temperature superconductivity, which involves the combination of electronics, computers, ceramics, and manufacturing technologies, provides another telling example of U.S. weakness in hybrid innovation.[63]

High-definition television (HDTV) illustrates our weakness in systems technology. HDTV promises to make current television systems obsolete and open huge new markets for microelectronic products and applications. The global market for advanced television systems alone is expected to reach $30 billion by the year 2000, and go as high as $500 billion by the year 2020. Many believe that HDTV is a critical "enabling technology" with important ramifications for a host of technology fields and industries. HDTV will revolutionalize the home entertainment industry, creating new markets for video compact discs, laser printers and turntables, video libraries, and even "computerized" television.[64] These products provide an enormous demand for an entire spectrum of electronics components. It has been estimated that the demand for memory chips for HDTVs could be five times larger than the total demand from the computer industry.[65] HDTV will fuel a host of related innovations in fields like display technology, imaging systems, medical diagnostics, and even radar systems. And sales of HDTV products will provide the capital needed to undertake huge investments in new digital communications infrastructures such as fiber optic lines, which can handle increased electronic data loads. Hugh Carter Donahue observes:

> Cable and VCR transformed television in the 1970s and 1980s, providing unheard of flexibility in programming. High-definition television promises to have an even greater impact by the 1990s. HDTV sets will show high resolution pictures on large, extra-wide screens and will produce the crystal clear sound of a compact disc. They may also be smart enough to store and retrieve electronic still pictures, allow two way video communication, and receive programming from broadcasters, cable, satellite, and perhaps even fiber optic phone line.[66]

But the United States is already behind in the race to HDTV, as large Japanese companies like Sony, Matsushita (Panasonic), Toshiba, and Hitachi consolidate their lead in television and video electronics. Steven Jobs sums up the current condition of the U.S. HDTV effort: "All this stuff about how the US. is going to participate is a joke. . . . We've lost it already."[67]

The reason for our failure in hybrid innovations and systems technologies are easy to understand. The small high-tech companies of Silicon Valley and Route 128 lack the scale, resources, and long-term outlook that are needed to develop these types of products. When companies make just one version of a product or produce just one part of a product, they have neither the breadth of in-house expertise necessary to create important hybrid innovations nor the large numbers of R&D personnel necessary to undertake a large systems innovation. In the words of Regis McKenna, the high-tech marketeer and part-time venture capitalist: "Small companies are great product innovators, but they have limited resources. They can initiate innovation, but few can sustain it."[68]

The Missing "Consumer Connection"

The problems of our HDTV effort illuminate a critical issue facing American high technology: the huge chasm that separates the innovative high-tech firms of Silicon Valley and Route 128 from our traditional consumer products industries.

This is a two-way street. On the one hand, few leading U.S. high-technology companies make consumer electronics goods.[69] Small entrepreneurial companies that have tried to enter mass production fields have usually failed. For example, when Intel and Texas Instruments tried to get into radio and digital watch production, they were quickly annihilated by large Japanese companies. On the other hand, large electronics companies, such as GE and Westinghouse, are certainly not important producers of cutting edge commercial high technology. Most of the high-technology producers produced by these companies are for military applications. Large U.S. electronic companies would rather produce for the lucrative defense sector than make commercial products.

There is little connection between small high-technology firms and large consumer electronic companies, so they do not reinforce one another's activities. Consider the following facts. Just 6.4 percent of all U.S. semiconductors sales are to consumer electronics companies.[70] The vast majority of semiconductors are consumed by other high-technology sectors, for example, computer and telecommunications firms and the military. The result is that American semiconductor industry is left with a narrow and volatile market base. American microelectronics as a whole misses out on the potentially huge profits and reinvestment capital that can come from using high technology to make better consumer products. American high technology is faced with a missing "consumer connection."

This missing connection is even more disastrous for the consumer electronics industry. This chasm makes it difficult to apply and use new technological developments to upgrade and improve older products. As a consequence, the US. consumer projects industry has fallen far behind those of Japan and Western Europe. The U.S. Semiconductor Industry Association recognized this problem in 1989: "Our international competitors are far ahead of us in developing advanced electronics applications via the consumer market segment. We, as an industry, and as a country, must pull together quickly. . . before our competitors have an insurmountable lead. . . America's future industrial viability and electronic leadership could well be at stake."[71] The situation is so serious that a presidential commission on the semiconductor industry issued a report in October 1989 calling for the establishment of a new multibillion-dollar Technology Corporation of America to resurrect the consumer electronics industry.[72]

Large Japanese companies are able to use microelectronic innovations to develop cutting-edge consumer electronic goods such as Watchman televisions, CD players, miniature tape players and recorders, and a wide range of other products. But Japanese corporations are also using advanced technology to revolutionize the "white goods" industry by applying high technology to everyday needs such as cooking, keeping food cold, and washing clothes. Take the example of a simple standardized commodity, the home washing machine. Japanese washing machines use chips to replace mechanical parts. As a result they are quieter, more reliable, and less expensive to produce than American washing machines, most of which are still made with mechanical gears.

In biotechnology, the missing consumer connection is also evident—but in a different way. Start-ups work on narrow-niche technologies but lack the marketing networks for the products they develop. Large companies are unable to secure the best researchers and thus must purchase marketing rights to fill out their existing product lines. For this reason the new technologies of biotechnology are not adequately integrated into the knowledge base of the firm. In addition, a variety of promising uses for biotechnology ranging from food processing, mining, and vast cleanup either go unaddressed or move along at a slow pace.

Enclaves of Restructuring

Perhaps the most striking shortcoming of Silicon Valley and Route 128 is that their model of technological and industrial organization has done little to transform basic manufacturing industries like consumer electronics or automobiles. In fact, the major organizational innovations (e.g. R&D teams, equity ownership, decentralized decision-making) associated with this model are virtually unheard-of in large Fordist industrial corporations. It is as though high-technology start-ups and large industrial companies are operating on entirely different planes.[73]

This is apparent in the strained relationships between microelectronics companies and the automobile industry.[74] High-technology entrepreneurs and the straitlaced managers of General Motors and Ford think on entirely different wavelengths. Rapid technical change and the ability to make fortunes overnight create a contemptuous attitude among high-technology executives for what they consider a backward "Rust Belt mentality." Automobile executives, in turn, have a distaste for idiosyncrasies of "hot-shot" entrepreneurs. The constant strife between H. Ross Perot, formerly of Electronic Date Systems and Roger Smith of General Motors was just one example of this. According to Robert Palmer, an expert on relationships between the automobile and semiconductor industries, "automotive buyers attempt to treat the electronics as a rustbelt industry. . . . There's more stated partnership than real. . . . Semiconductor companies tend to send signals that they have a lack of patience with metal benders. They have a technical arrogance."[75] The lack of trust and communication between high-tech firms and Big Three automobile companies means that American cars contain a relatively low level of microelectronics, and what microelectronics and what they do to possess is less than state of the art. Our own study of component parts suppliers to the Japanese "transplant" automakers in the American Midwest reinforces this conclusion: Japanese companies have experienced great difficulty getting microelectronics parts from U.S. producers and continue to import them from Japan.[76]

It is naïve to think that the model of high-technology organization found in Silicon Valley and Route 128 can save us from the challenge of heightened global competition. While this model gives rise to new, highly innovative companies at breakneck speed, it also generates a high degree of internal competition and a serious problem of industrial fragmentation. It can catalyze the world's most advanced breakthrough innovations, but it is unable to generate the small product, process, hybrid, and systems innovations that are needed to follow-through on such innovations and turn them into a wide variety of commercial products. In the end, Silicon Valley and Route 128 remain two limited enclaves of restructuring that have been unable to transform the main body of the U.S. economy either through the diffusion of their organizational practices or by setting in motion the "gales of creative destruction" that can reinvigorate and renew traditional industries. Even though the present U.S. "breakthrough" model of high-technology organization can find rich veins of technology opportunity, it is unable to mine those veins fully.

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