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Learning the Silicon Valley Way

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By Gordon Moore and Kevin Davis

Comments Welcome

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ABSTRACT:

"Learning the Silicon Valley Way" is the incremental process of firm-building and market-building that underlay the formation of the world's preeminent high-technology, high growth economy. Revisiting Moore's experiences as an early employee of Shockley Semiconductor and as a cofounder of Fairchild Semiconductor and Intel, we emphasize the necessary conditions for the take-off of Silicon Valley. These conditions include broad-based learning of the many facets of managing commercial scientific endeavors - from managing internal incentives to limiting the dimensions of external competition - and the central importance of a large technological opportunity. At the same time, we reevaluate and downplay the role that military spending, university proximity, and central planning played in the evolution of this economy. The end result is an almost iconoclastic, and we believe, more accurate picture of the crucial elements in a nascent high-tech regional economy.

Gordon E. Moore *is widely regarded as one of Silicon Valley's founding fathers. Moore came back to his native California in 1956 to work with Shockley Semiconductor. His membership in the "Traitorous Eight" who left to start Fairchild Semiconductor in1958 places him at the top of most 'genealogies' of Silicon Valley. Co-founder of Intel in 1968, and now Chairman Emeritus, Moore is perhaps best known for his 1965 prognostication on transistor density now universally known as "Moore's Law." His forty years of work in semiconductor technologies in Silicon Valley give him a unique perspective on the evolution of the semiconductor industry and the valley he helped shape.*

Moore is a member of the National Academy of Engineering, A Fellow of the IEEE and a Chairman Emeritus of the Board of Trustees of the California Institute of Technology. In 1990, President George H.W. Bush bestowed upon him the National Medal of Technology.

This chapter is co-authored with Kevin Davis, Ph.D. candidate in economic history at Stanford University.

Introduction

As someone fortunate to have had some success in the business of technology, from time to time journalists and researchers contact me to ask about my experiences in the semiconductor industry here in Northern California. Most have sought in some way to define and understand the birth of this place called 'Silicon Valley.' This chapter is, in part, an addendum to and clarification of their efforts. Charting the establishment of this dynamic is fundamentally different than appreciating its operation. My co-author and I have tried capture what we feel are the crucial elements of the early history of Silicon Valley through the retelling and reexamination of my personal experience.

We hold that the central element in the history of Silicon Valley is the founding of a previously unknown type of regional, dynamic, high technology economy. A set of transformations took place in which scientists and engineers of this particular economy learned to organize themselves and their businesses differently – transforming science into business – to take advantage of a significant technological opportunity. These transformations involved learning to build firms and markets in ways unique to high technology products, and often unique to the particular product at hand. Central to these developments was the size and nature of the technological opportunity that induced it, as more than government contracts, university advocacy, or sunny weather, the opportunity defined the creative response.

It is our hope that our reflections on my firm-level experience during the founding of Silicon Valley will clarify how these changes took place, and their central role in the establishment of the Silicon Valley-style economy.

A caveat: Comparing my own experience with the plentiful historical analysis of Silicon Valley is not always straightforward. Although collectively Shockley, Fairchild and Intel span the history of the 'silicon' in 'Silicon Valley,' the story of the birth of this dynamic economy rightly encompasses more than one industry. And certainly some of the challenges to the development of semiconductors were unique to that industry. We do not attempt to tell the whole story of what happened in the valley. This limited scope enables us to avoid a common mode of thinking about this history – a mode that confuses the set of conditions and events that proved to be *sufficient* for the evolution of Silicon Valley (or any similar dynamic regional economy), with those conditions and lessons that were *necessary.*

Beyond the figures and dates that comprise an encyclopedic accounting of events, we believe there is a neglected analytical story of evolving institutions and knowledge that can provide insight for technologists and policy makers. Our story focuses on what those who started and built these companies and the lessons learned in technology business and organization that were *necessary* for the region to evolve into a dynamic high-technology economy. In so doing, we also find ourselves questioning some pre-conditions often presented as crucial, which we feel were not. In this sense, the historical analysis we present here is less all-encompassing, but we hope more precise.

Avoiding the Misdirection of Previous Histories

In many authors' renderings of Silicon Valley history, elaborate descriptions of businesses and practices capture a technical, institutional, or cultural snapshot of a particular moment in Silicon Valley time. These are often powerful and useful observations. But when these snapshots are then used to project backward into causes and forward into outcomes, this can be disastrously misleading. Lost in this practice is the essential progression to the events and circumstances influencing this course of development. What 'works' right now in this dynamic, regional, high-technology economy tells us little of how precisely Silicon Valley came to be just such a place, or how any such place comes into being. The potential disaster lies in the fact that these static, descriptive efforts culminate in policy recommendations that resemble recipes or magic potions, e.g.:

COMBINE LIBERAL AMOUNTS OF	TECHNOLOGY,
	ENTREPRENEURS,
	CAPITAL, *AND*
	SUNSHINE.
ADD ONE (1)	UNIVERSITY
STIR VIGOROUSLY.	

At other times, authors fall prey to the two most common (flawed) tendencies of all who write history. The result of these tendencies has come to comprise a common 'mythology' of Silicon Valley.

The first of these flawed historical modes over-emphasizes 'contingent moments' – either events or truths realized – in which the actions of a particular person, a particular innovation, or even some accident has made possible this high-tech phenomenon in a defining flash of truth or insight. The opposite extreme is the mode of constructing an historical 'inevitability,' where current successes arise from a crescendo of forces that trace back to the Gold Rush, and beyond. Among the many myths established in these modes: that the unique Silicon Valley start-up mentality began with the turn-of-the century private investments of Stanford University president, David Starr Jordan; that Dean of Engineering Fred Terman and Stanford University somehow orchestrated the creation of Silicon Valley by cleverly cajoling a 'critical mass' of industry and assembling the 'right' supporting resources; that an unstable Nobel laureate (Bill Shockley) who simply needed to be near his mother induced the start-up mentality in this place; that a defining few of us (the so-called ‘Traitorous Eight’) ‘invented’ start-ups in departing Shockley to establish Fairchild.

These histories and the myths they establish linger perhaps because they resonate both with those who believe in the uniqueness and irreproducibility of Silicon Valley that these individuals represent (contingent thinkers), and with those who think duplicating this system is just a matter of proper central planning (inevitability theorists). Either interpretation seems to ignore the progression of effort, discovery and learning at the heart of our experience.

Our Approach

Herein we tell the story of the learning that lies at the core of the transformations that built Silicon Valley. It is our contention that the success and structure of modern Silicon Valley stems more from this incremental process of learning these particular lessons, than from any one person, company, or organization. Below, we highlight some of this necessary learning – lessons that had to be learned in and ‘by’ Silicon Valley in order to be successful in that time.

We present these lessons through stories and reflections – which will seem familiar to some – and through our further joint discussion of how these stories and reflections relate to the existing historical analysis and policy questions – which will not. For clarity’s sake, we have tried to group these lessons into five categories, coupling my personal story with our joint discussion of important points and clarifications. Our categories are somewhat arbitrary, and there is naturally a great deal of overlap, but they have come to reflect my understanding of the unique and noteworthy components of the founding and evolution of Silicon Valley.

Lesson I: Scientists Learning to be Managers

The Story:

After deciding that he wanted to find success in business as well as in the lab, William Shockley brought the silicon to Silicon Valley in 1956. For the most part, those of us who came to work for Shockley and his fledgling semiconductor operation were scientists accustomed to spending our time in the lab. We had little experience managing people. Of course, neither did Shockley. But his charming recruitment assembled a talented group of people, mostly with no background in semiconductors, to develop the technology to produce silicon transistors.

Over time, however, in ways that seem to have become almost legendary, Shockley's approach to management made it almost impossible for us to succeed. Although later we too would learn all about the real fear of losing workers (and work) to competitors, Shockley developed traits that you could only describe as paranoid. He caused a lot of division within our small group with his 'secret project as important as the transistor' – about which half of us were not to be told. He suspected that members of his staff were purposely trying to undermine the project and prohibited them from access to some of the work. Any new results from our lab had to be checked with his previous colleagues at Bell Labs before they were accepted. It became generally difficult for us to work with each other as well as with him. In what was probably the final straw, he decided that the entire laboratory staff should undergo polygraph tests to determine who was responsible for a stray nail that caused a minor injury to one of our office staff.

The group was on the verge of breaking up. In fact, a few of the first recruits had already abandoned the lab. Aside from the destructiveness of his managerial methods Shockley had decided to change directions technologically, switching the targeted product from a transistor to a four-layer diode, a much less generally useful device. When an opportunity arose, we tried to out-maneuver Shockley and get him moved aside in the organization. A group of us met with Arnold Beckman (of Beckman Instruments, which had funded the Shockley operation) to explain to him how Bill stood in the way of us accomplishing anything. We had hoped Beckman might obtain for Bill a professorship somewhere (perhaps Stanford), where he could serve only as an advisor to our operation. Ultimately Beckman's loyalty won out and our attempt backfired, and in the process we had burned our bridges. It was time to find something else to do.

Shortly thereafter, eight of us left and ended up starting Fairchild Semiconductor Corporation. (How and why that happened is part of a wholly different lesson. We'll get to that later.) Even at that point, I don't think you could say that we were entrepreneurs, but we had learned something along the way. We had learned from the Shockley experience that more than mere technological know-how was required to be successful. None of us knew how to run a company. The first thing we had to do was find someone to run our company. We had to hire ourselves a boss.

So we advertised for a general manager. Buried among the many applications from salesmen who believed they could manage was an application from Ed Baldwin, the engineering manager for the Hughes Semiconductor operation, then one of the largest semiconductor companies in the world. We hired him, and under Ed's leadership Fairchild took on the job of designing and manufacturing the double-diffused silicon transistor. This important product had been constructed in the laboratory at Bell, but no one had figured out how to produce it at a commercial scale. We set ourselves the task of developing that new production technology.

Without Ed we might have floundered. He brought to Fairchild Semiconductor the knowledge of the simple things that every M.B.A. knew (in general), but within a technological context. For instance, we had no idea that we had to structure an organization or how to go about doing that. We didn't know to set up a manufacturing department and an engineering department and a sales force. He taught us that the different parts of the organization should be established with different responsibilities; for example, you have to set up a manufacturing operation separate from the development laboratory. You have to engineer and specify manufacturing *processes*, which is completely different from getting something to work once in the lab. Manufacturing specifications had to be documented to assure that the products produced remained consistent over time. Ed even had us hire our first marketing manager. All these things sound obvious, but we didn't know them, and they take a while to figure out.

With Ed's direction, everything was working fine: the development and pre-production engineering for our process and first products were complete; the various parts of the organization were functioning and working together; we had a thick process-spec book that recorded all the detailed recipes; and we had interested customers.

But then Fairchild suffered the first of its many Silicon Valley spin-offs. One day we came to work and discovered that Baldwin, along with a group of people he had suggested we hire, were leaving to set up a competing semiconductor company (which became Rheem Semiconductor) just down the road. He and his group took with them the recipes for manufacturing we had just developed. It might have sunk us.

But what they left behind was something much more valuable. Baldwin had educated a class of technologist-managers who now had the ability to go it alone. Rather than hire an outsider again and risk another defection, we decided to look internally for our new leader. And so Bob Noyce became our new General Manager. Our response to the establishment of Rheem Semiconductor was to compete technologically – by improving upon the products we had developed while Ed was our boss, and then beating them to market. Although a court eventually ruled Rheem had misappropriated trade secrets, it no longer mattered. We were well on our way.

*   *   *

Our Discussion:

In this lesson and the next we emphasize the central role of firm-building in the genesis of Silicon Valley. This process of organizing resources and personnel into a profitable company necessarily developed new modes and requirements in semiconductor firms. These changes are at the heart of the development of Silicon Valley. Foremost among the changes that occurred within the firm, was the evolution and proliferation of the technologist-manager.

The Technologist Manager.

The state of semiconductor technology in 1957 was such that it was not clear how to go about setting up a business in semiconductor devices. Starting Fairchild was an exercise in building a business on the frontier of basic science. But the methodologies of laboratory organization of science don't tell you how to manage independent minds, how to divide people into jobs and tasks, or how to organize a workplace or market strategy.

We assert that this process of firm-building lies at the heart of understanding regions like Silicon Valley. Those individuals that possess both technical insight and business capability – the technologist-managers – are the firm builders who do the hard work of making viable enterprises out of science. The development of the technologist-manager was essential to the changing dynamic of this regional economy, and a necessary condition for the formation of the unique structure and success of the Silicon Valley semiconductor industry.

There are many components to the technologist-manager that we see beginning to take shape early in the founding of Fairchild. Enumerated here, these components become ever more clear in the ensuing lessons.

- **Managing personnel and the firm**. Aligning the goals and incentives of the firm with those of the talented individuals whose efforts build a successful firm takes on greater importance in highly technical, skill-intensive firms. The goals of the firm must be clear, and the payoffs for employees certain. The scarcity of these trained scientists and engineers makes them difficult to replace. Moreover, especially in high technology firms, employees quickly develop project- and firm-specific knowledge. When the opportunity to apply that knowledge (outside the current firm) is great – i.e. in most high technology businesses – the costs of mismanaging personnel become greater.
- **Structuring a technology business**. Dividing tasks and building a firm so that the parts add up to something is a complicated process when scientific exploration is involved. This process involves establishing technological product goals, and creating an organization that can achieve those goals of reproducibility and mass production. Fairchild was as different from the university laboratory as it was from the standardized production facilities fabricating and assembling goods. The mode of single-shot discovery or invention in the laboratory had to be expanded to explore highly technical processes of mass production. Early 20th-century mass production mentality had to incorporate much more highly technical and evolving manufacturing methods.

- **Managing discovery.** Within that well-structured technology firm, the technologist-manager had to learn to guide innovation with an understanding of both commercial and technical goals. These managers need first to be scientists with a deep understanding of the subject. But the demands of the firm mean that the generality typical of the university style lab is far too inefficient. These technologist-managers need to be able to plot the shortest path to workable discovery.

Rather than representing simply a discrete shift in management style or technique, the technologist-manager is emblematic of a widespread human-capital deepening. This new human capital, which could only be developed through experience, linked technical possibility and market need. While perhaps competent technical management is unremarkable today, this kind of technical leadership was extremely rare in 1957. Notable examples exist in earlier science based industries (e.g. mining, chemicals) and even local stand-outs (e.g. William Hewlett). Nevertheless, this was not generally a skill that could be purchased. This leadership didn't simply float out of some university, industrial, or military organization either.

The ubiquity of the technologist-manager was, of necessity, built in this time period. The role of Fairchild in this process is not to be understated. Managers and entrepreneurs in Silicon Valley long spoke of the importance of "Fairchild University" as a educational, managerial training ground.[1] The nature and scope of this training also belies the difference between Fairchild and universities or other types of lab employment. Of necessity, scientists were learning about managing discovery teams and building commercial processes for technology goods. But they also learned about the writing and reading of annual reports, capital asset and inventory management and depreciation, and role approaches to distribution and accounting affected their profits.[2]

The birth of 'Silicon Valley' and the role of Stanford

One of the first things to notice in this chapter is that our story doesn't begin with electronics, military spending, or Stanford. This reflects our assertion that the introduction and expansion of semiconductor technologies began a new and unique growth trajectory in Santa Clara County. In beginning our chronology with the founding of Fairchild, we assert that growth based on compounded innovation and the flexible modes of business and entrepreneurship that characterize the Silicon Valley have their roots in the silicon semiconductor industry. That this is so should be evident not only from its

[1] Annalee Saxenian, *Regional Advantage*. Cambridge, MA: Harvard University Press. 1994. p.31

name and the timing of its designation, but from the many previous attempts to categorize and trace the network effects and the origins of the many new firms that came to the valley beginning in the 1960s.[3] These 'genealogies' [4] trace the linkages of all of the early semiconductor concerns through key personnel, with each linking back to Fairchild and Shockley. Indeed, a survey of engineers at a Sunnyvale semiconductor industry conference in 1969, found that all but a couple dozen of 400 in attendance had worked at Fairchild at one point in his career.[5] It is also notable that not one of the eight founders of Fairchild had ever been employed in a Santa Clara County firm prior to Shockley Semiconductor, and most were in fact recruited from East Coast employment. Even Ed Baldwin came from elsewhere. This was a industry of transplants.

Yet still many take exception to beginning Silicon Valley's history as a unique economic region with the birth of the semiconductor industry, claiming in one form or another, as is done in a recent collection on the region, "Silicon Valley is nearly one hundred years old."[6] This history and others like it[7] peer into the history of the region and seek out those elements that ring true to current Silicon Valley self-conceptions.

Based on the histories of Bay Area firm and industry foundings from early in the last century (in technologies from telegraph to vacuum tubes to radio), we believe these deep roots historical claims miss an important point for policy makers and economists: Semiconductor devices were a profound technological opportunity at the frontier of science – an opportunity perhaps greater than any seen in this valley before – that the founders of these semiconductor companies identified and intended to exploit for commercial gain. It is true that Silicon Valley did not magically appear virgin soil. The Bay Area had known commerce, entrepreneurial firm formation, and even technology firm formation before 1957. But that it had was neither on the minds of, nor terribly relevant to, the resources availed of by the 'Traitorous Eight" as they started their firm. This tremendous technological opportunity did not simply permit an easy imitation of existing local business models or modes of discovery. The importance of the collective response to this opportunity and its unique new knowledge requirements begin to explain our interpretation of the 'when' of Silicon Valley's formation.

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[2] Moore notes that this second learning component came somewhat more painfully after parent company Fairchild Camera had creatively accounted themselves a lower Fairchild Semiconductor valuation at the time of their buyout. Nothing teaches like necessity, it seems.

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[4] The most famous of these was begun by Don C. Hoelfer, who authored the popular local tabloid Microelectronic News and coined the term Silicon Valley. The chart is maintained and available in poster form today by SEMI (Semiconductor Equipment and Materials International.

[5] Saxenian, 1994. p. 31.

[6] Timothy Sturgeon, "How Silicon Valley Came to Be" in *Understanding Silicon Valley,* Martin Kenney, ed. 2000.

For all its current importance as a participating member of the Silicon Valley economic community, we do not hold Stanford University to have been essential to the *formation* of Silicon Valley. The essentials of Fairchild's founding belies this somewhat provocative claim – not for what was *necessary*, but for what we propose was helpful, but *not necessary* at this early juncture. Specifically, the defining characteristics of Silicon Valley business modes and models, and the sustained, rapid, technology-based growth were neither started nor made fundamentally possible through the presence of this university.

Within the existing histories, Stanford's role as a conduit for military research and expenditure is credited with spillovers to local industry, including the attraction of an electronics industry. Additionally Stanford - or more specifically former Dean of Engineering Fred Terman - is credited with the active recruitment of firms to the local area, with providing early and important financial support, and with providing, via the university, the inclination to communicate among firms and with the academic world.[8]

Like most American universities, Stanford was transformed by the Cold War, becoming in many ways an institution in service to society rather than apart from it. Fred Terman's role in Stanford's particular transformation and rise to prominence was considerable. The years following World War II saw an explosion of federal funds for research in defense, and Terman was a successful advocate for the exploitation of postwar federal patronage. It is true that some electronics firms did grow out of this university research, and the San Francisco Bay Area did find itself home to a growing electronics industry. But the clustering of high-technology firms into 'science regions' around universities was notable throughout the country, and yet no other regions experienced Silicon Valley-style transformation in the decades hence. Likewise, Stanford was not alone in setting up an Industrial Park and attempting to directly bring firms to the university community. Finally, the personal efforts of Fred Terman in funding local ventures, were personal (not institutional) efforts not unlike those taking place in countless other places around the country.[9]

Much has also been said about the important cultural innovations supported by Stanford and Terman. It was Dean Terman's goal to increase ties between business and academic circles. He encouraged faculty to be entrepreneurs. Stanford created an unparalleled Honors Cooperative Program, designed to bring engineers into the classroom for continued learning and mutual benefit. We assert that this advocacy and its results – although they parallel norms of behavior seen as important today – were secondary in importance to the opportunity that semiconductors represented. The size of the opportunity,

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[7] One such notable history, "The Making of Silicon Valley: A One Hundred Year Renaissance" published by the Santa Clara Valley Historical Association, was turned into a PBS Documentary hosted by Walter Cronkite.

[8]

and the learning about firm-building and market-building that took place in the semiconductor industry could have overcome a less welcoming external environment.

Another more recent former Dean of Engineering Jim Gibbons has written on the varied influence of Stanford in different industry sectors, or even over the life of a single company. Still today, after more than 40 years of sharing the valley with the semiconductor industry, he notes that while "important device and fabrication technologies for the semiconductor are indeed developed at Stanford and elsewhere… most of the development of semiconductor technology occurs in the industry itself."[10]

In 1960, Stanford established departments in chemical engineering and materials science – areas that comprise the core of semiconductor research – but of course only began to graduate students or create valuable semiconductor knowledge some years later. While exemplary in this response to local labor market needs, Stanford's establishment of these departments was neither unique nor determinative. Even at this late stage Stanford's main role in the semiconductor industry is its yearly provision of outstanding M.S. and Ph.D. graduates. In a country with such mobile labor markets as the U.S., the local presence of a university seems hardly to have been a necessity.

Truly, the value of the local firms touched by Stanford has been considerable. Dean Gibbons calculates that since 1988,the revenue of firms formed by Stanford teams and technology comprises approximately half of the total revenue of Silicon Valley firms.[11] Obviously we don't seek herein to argue against the beneficial role that Stanford has played in the economic structure of Silicon Valley. HP, Varian, and other such firms are here because Stanford was here at their formation. But let us guard against overstating Stanford's role in the formation of Silicon Valley's salient characteristics. Neither HP, nor Varian, nor Lockheed, nor Stanford brought semiconductors to Santa Clara County, and their presence was not critical to the Silicon Valley-defining modes of business developed in that industry. To quote Gibbons' conclusion, "for all this to happen, it was first necessary for Fairchild to spin out of the Shockley Semiconductor Laboratory, thus proving that employees could leave the company they were working for and start a competitor to it."

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[9] Rebecca Lowen (*Creating the Cold War University: The Transformation of Stanford.* 1997) discusses Fred Terman's role in Stanford's development at length. This discussion notes that much of what happened at Stanford occurred at many universities across the country.

[10] James Gibbons, "The Role of Stanford University: A Dean's Reflections" in *The Silicon Valley Edge*, edited by Lee, Miller, Hancock and Rowen. Stanford University Press, 2000.

[11] Quoting Gibbons on his calculation methods: "*A Stanford start-up is a company in which both the technology for the first product and a majority of the founding team came from Stanford.* This definition is not intended to distinguish between technology that was actually developed by the founders at Stanford and technology that they learned about in the normal course of educational programs." The revenue calculations are done fairly late in the development of Silicon Valley, in the years 1988 and 1996.

A better way to think of the primary role the university in this and other regional high-technology economies is as an economic institution responsive to the manpower and intellectual needs of the marketplace.[12] American universities are a backbone of technological leadership regardless of location, and may be an essential integrated part of a sustained dynamic regional economy. Our claim, therefore, is one of clarification, on what we feel was the purpose of the local university in the *founding* of this region, and on placing Stanford's tremendous utility properly within the chronology. As an institution in response to the needs of the industrial community, Stanford has been exemplary, notably operating in many of the roles envisioned for the university by promoters such as Terman. Stanford now graduates large numbers of advanced degree engineers and scientists that work directly in the valley, and boasts many partnerships with corporations in research that build better future employees. The past decade has also seen an increased sponsorship and support for entrepreneurial activity in structured competitions and classes. But this recent acceleration of influence in the valley highlights the difference between the emergence of Silicon Valley and a mature regional economy. Understanding Stanford's place in the formation of Silicon Valley is as much a question of 'when' as 'how.'

Lesson II: Commercial Science

The Story:

I began my career in semiconductors by coming to work for Shockley primarily because of my growing interest in the commercial aspects of science. I was doing basic research at the Applied Physics Laboratory managed by Johns Hopkins at the time, and I recall calculating one day that the work in my lab was costing the taxpayer over five dollars per published word. I thought I could – and wanted to – do something more useful. Pure research with no practical use that I could imagine just wasn't working for me. I decided it was time for a change. That change began my shift from a purely scientific toward an engineering mentality.

The difference between the scientist and the engineer to me is a subtle difference in motivation. The scientist is seeking new knowledge—a better or more complete picture of the contents of the universe. The engineer, on the other hand, wants to achieve a particular result, a new structure or

[12] Stanford economic historian Nathan Rosenberg has written extensively on the role of universities as economic institutions– noting that one of the major developments in the years since the Second World War has been that some universities are now producers of technological knowledge that is not very far from potential commercialization. In his internationally comparative work, however, Rosenberg notes some reasons for the singular nature of American

electronic device, for example. Often, especially in a company at the forefront of technology, the engineer needs understanding every bit as fundamental as that sought by the scientist to achieve his desired result. But the engineer seeks and utilizes that knowledge differently. Building a company around the new technology of semiconductors was about learning to create and retain the knowledge that enabled us to build useful, profitable products.

At the time of the founding of Shockley Semiconductor Corporation and Fairchild much of the underlying physics and chemistry relating to semiconductors and their related processes was not known. In addition there were no universities producing "semiconductor engineers." It was a new field and fell between the cracks of the usual academic departments. Electronic devices made by chemical processing fit neither electrical engineering nor chemistry. As a result, these people with basic science backgrounds made the early contributions to developing the industry.

The transition to commercial, product-driven science as we know it today didn't take place over night. Unlike firms that build commercial products on the backs of university or military science, Shockley and Fairchild were plowing virgin scientific soil. New technology often ran ahead of understanding, with science struggling to catch up. For a decade the basic research in semiconductors was the province of the semiconductor industry alone. So as they grew, companies such as Fairchild built large research and development laboratories. By and large, these were labs of a different nature and approach than their military or university counterparts, as a result of the different outcomes we sought.

Bob Noyce formalized the idea behind this different approach with his proposed principle of 'minimum information' for efficient engineering. In this 'minimum information' framework, a researcher guesses what the answer to a problem is and goes as far as he can in a heuristic way. If that doesn't solve the problem, he backs up and learns enough to try something else. Thus, rather than mounting complex and expensive research efforts aimed at a deep understanding of the all the facets of an effect (and aimed at producing publishable scientific answers) our scientist-engineers try to get by with as little information as possible to make something that works. Developing a deliverable product is the only goal.

Another advantage to operating on the principle of minimum information: the company generates fewer spin-offs. This is the reason, I believe, that Intel's R&D capture ratio is much higher than Fairchild's ever was: because it does not work to generate more ideas than it can use. We came to realize that running a centralized, general research lab was just too inefficient in that the capture ratio is low and the difficulty of (internal) technology transfer is high.

This is the second part of this lesson about building a commercial technology company: We had to learn not just about the creation of new technology, but also about how we transmitted that knowledge

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universities within the western world. Chief among these is their *responsiveness* to the manpower and intellectual needs of the marketplace.

throughout our organization. Managing technology transfer is a critical and difficult task. As a result, another thing that changed dramatically from Fairchild to Intel, and still varies a great deal in the valley, is the relationship of the R&D organization to the whole firm.

Fairchild Semiconductor invested in excess of 10% of its revenues in what grew into a 600 person, stand-alone R&D organization. As we were working in the right technology and functioned quite effectively, the laboratory was highly productive for us for some time. Then, in the late 1960s, our R&D organization began to have difficulty transferring new products and technology to the product and production divisions. We found that the more technically competent the production teams became, the more difficult it was to transfer something new to them. They were less willing to accept the processes that we created for them. They wanted to redevelop it rather than take what had already been done. One frustrating example of this struggle was seen in the Fairchild experience with the MOS (Metal-Oxide Semiconductor) technology. We had stable devices in the laboratory in 1961, and still by the time I left Fairchild in 1968 they were not yet in successful production. Meanwhile a second-generation spin-off - a spin-off of one of our spin-offs – had succeeded in producing MOS devices by then, using exactly what Fairchild had long before learned in the lab.

So when we set up Intel we decided we would avoid that split between R&D and manufacturing. We'd be willing to accept somewhat less-efficient manufacturing for a more efficient technology transfer process. In order to avoid the difficulties of internal technology transfer, we made the R&D people actually do their development work right in the production facility and we have continued that (with some variation) ever since. Intel still recruits a number of the best PhDs available and spreads them throughout the organization rather than concentrate them in a central laboratory.

Some observers have argued that defense department spending 'bought' Silicon Valley through support and development of these technologies.[13] Implicit in this story of the focus and learning accomplished in the growth of Fairchild, however, is that from our perspective, the impact exerted by defense R&D spending was quite small. Contrary to what may have been thought or alleged, the space program in the 1960s had a negligible impact on the semiconductor industry. On the whole, its requirements for quantities were very small. Their engineering approach was extremely conservative so that only essentially obsolete components (from the perspective of the growth of the technology) were used for the program. About the only defense spending that did have an appreciable impact for Fairchild was that for the Minuteman I and Minuteman II missiles. Minuteman I probably hurried our refinement of the planar transistor, and Minuteman II did supply the first volume market for a large variety of integrated circuits. But by the mid-1960s what was largely a market-padding influence evaporated, and the military has not had an impact on silicon product development since. To be fair, we may not be representative of the industry as a whole. But the defense contracts *per se* had minimal direct influence on either the direction or outcomes of our research or product agendas.

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Our Discussion:

Science inside the private firm

The path to the success for Fairchild and Intel required orienting the process of scientific discovery towards profit-making goals. This required changing long held intellectual habits and modes of day-to-day decision-making common to scientists. To do science for commercial ends, scientists had to move away from the academic approach of lingering on understanding the basic and abstract features of phenomena. Making sure that something worked in practice (even though not necessarily optimally) and at proper costs was and remains more important. Unlike university settings, industrial research relies more on experimentation (trial and error) and "hands-on" engineering than on abstract theorizing. Pure science can be too slow, hindered by having no concept of 'good enough.' Military contracts regularly suffered from the same scientific misdirection, which is precisely why they did not guide the research agenda at Fairchild; for military specifications, 'good enough' wasn't.

Commercial orientation and the role of the military

The commercial success of Fairchild, and of the many successful companies it spawned, can be traced back in part to the early commercial orientation of the firm. A study by Holbrook, *et al* of four players in the early semiconductor industry – Sprague Electric, Motorola, Shockley and Fairchild – highlights some of the uniqueness of Fairchild in this way.[14]

Contrasting the four firms' early histories, Holbrook, *et al* note that Sprague's post-war activity was (mostly) in military research. Likewise, Motorola was greatly influenced by their wartime work for the military – compelled expressly toward miniaturization. Shockley, ever idiosyncratic, was driven not directly by miniaturization, but novelty. "The impetus to miniaturize electronic circuits came from the armed services," they note. And "…military markets modulated [firms] strategy and behavior, at least in part. But not all firms targeted military markets." Least of all Fairchild. Of the four firms, all but

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Fairchild had, at the time of their entry into semiconductors, close ties to the military. They write that Fairchild was “the least well positioned of the firms with respect to the [existing military] market.” Fairchild, claim the authors, was driven by product performance and consistency.

Fairchild’s pursuit of customers did not lay in the distinction between commercial and military markets, but in pursuing the development of low cost, highly useful products. Or as Gordon Moore has also repeatedly stated, “We knew if we made a good product, people would want to buy it.” In the eyes of Fairchild’s founders, then, from the very beginning semiconductors were viewed as a general use technology.

Characteristic of this general-purpose understanding of the future of semiconductors is an early Fairchild practice chronicled by Silicon Valley and semiconductor industry historian Christophe Lecuyer.[15] Unlike other semiconductor firms, he writes, Fairchild Semiconductor emphasized the design of new applications in order to “broaden markets for existing products as well as to assist in developing markets for new products.” Fairchild needed to show how existing design problems were better solved with silicon. Their inclusion of ‘application notes’ became a fundamental component of their product, including circuit diagrams that many companies copied wholesale – for the production of everything from Hong Kong radios to Ford Motor Co. blinkers. One fundamental component of this commercial approach was to move the department of application engineering from R&D to marketing in 1961, so that these engineers could serve as a technical interface with customers.

Differing most significantly with our story, however, Lecuyer claims that this restructuring was a fundamental change in the way Fairchild set their research and product design agenda. In this telling, Fairchild sought ‘expansion’ into the commercial sector because of changes in military procurement policies and emerging demand elsewhere. “Born in the military sector,” he claims, “Fairchild Semiconductor gradually expanded into the commercial markets in the early and mid-1960s.”

Others have made similar claims regarding the intent of the early semiconductor firms. One author asserts, based on an Institute for Defense Analyses study on the role of government in the development of semiconductors, that “after the integrated circuit (IC)was announced, military orders poured in. Though the firms that developed the concept purposefully avoided military funding for their research so that the basic technology was privately owned, the motivation for developing the device was the announced intention of the armed forces to provide a substantial market for devices with the

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[14] Daniel Holbrook, David Hounshell, Wesley Cohen, and Steven Klepper, "The Nature, Sources, and Consequences of Firm Differences in the Early History of the Semiconductor Industry" *Strategic Management Journal*, Volume 21, Issue 10-11, 2000.
[15] Cristophe Lecuyer, "Silicon for Industry: Component Design, Mass Production, and the Move to Commercial Markets at Fairchild Semiconductor, 1960-1967" (History and Technology, 1999).

appropriate characteristics."[16] This fundamental mischaracterization of the motivations of Fairchild may result from a common distortion of the timeline and process for adoption. Another semiconductor history claim, "often new and better semiconductors are too expensive for industrial or consumer electronic products…As production proceeds, learning occurs and costs fall. Within a few years, the price is low enough to penetrate the industrial market, and eventually the consumer market."[17] As we will learn in the next lesson, Fairchild's experience with the integrated circuit directly contradicts this notion.

It has been rightly noted that military applications represented a significant portion of revenues for Fairchild and the entire semiconductor industry. Military contractors were lucrative early customers for Fairchild. But the importance of this market for the establishment and direction of the industry is frequently overstated. In no way did the government represent an 'angel' investor in the semiconductor marketplace, simply funding companies through targeted demand until they get off their feet, or even guiding the direction of research or product development. [18] These expenditures purchased semiconductor products, but did not guide their development, at least not at Fairchild. Military product requirements, it turned out, placed greater emphasis on reliability, measurability, and proven products than did the marketplace. As a result the products the military purchased were rarely at the leading edge of product development.[19]

The role of the government was nonetheless significant, in at least two ways. Very early on, it was the government (as part of an anti-trust settlement) that forced AT&T to share their findings on semiconductors freely. All four firms discussed above, save Fairchild (whose founders were yet too young) were formed under key personnel who attended a government funded Bell Labs symposium in 1951, where Bell released all their collected knowledge of transistors to the scientific community. This was the true birth of the industry. Government expenditure was undoubtedly determinative in many semiconductor firms' investment decisions and commercial successes, and significant R&D funds flowed into the industry, although not to Fairchild. Indeed, the policy lessons Holbrook, et al draw from the early history emphasize the potential benefits of broadly scattered government expenditure on finished technology products for the evolution of their competitive market. This blanket demand induces different

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[16] Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology.* Washington, D.C. : The Brookings Institution. 1988. p.17.

[17] Tilton, John E. *International Diffusion of Technology: The Case of Semiconductors.* Washington, D.C. :The Brookings Institution, 1971.

[18] This particular view has been emphasized by Stuart Leslie, ("The Biggest 'Angel' of Them All" in *Understanding Silicon Valley,* Martin Kenney, ed. 2000), without relating to the firm formation and fast changing industries representative of Silicon Valley.

[19] At a more basic level, there is a tendency to model the progression of new science to industry as traveling a particular path – from university or government laboratories into semi-commercial labs or government aided industries, and then through to fully private commercial viability. In fact, it is not uncommon for commercial activity to stimulate or alter the research agenda in the opposite direction. (For a discussion, see Nathan Rosenberg, "How Exogenous is Science" in *Inside the Black Box: Technology and Economics.* 1982)

technological approaches and doesn't 'pick winners.'[20] The bottom line for the semiconductor industry, however, may be a cautionary tale against over-dependence upon military expenditures. Following the direction set by military connections may have disinclined certain firms from the approach and technological breakthroughs accomplished by Fairchild.[21] So while we may view defense expenditures as broadly important to the development of transistors, and even somewhat helpful to early firms' bottom lines, neither the existence of Fairchild, nor the many cultural and economic innovations that followed in Silicon Valley, necessitated directive government investment.

Lesson III: Identifying, Creating, and Seizing Opportunities

The Story:

The 'Traitorous Eight' who left Shockley to form Fairchild had never intended to start a company. In fact, we had hoped to find a company that would hire our technical team, en masse. But one member of our group (Eugene Kleiner) had a friend at Hayden Stone, a New York investment-banking house. He wrote this friend a letter describing the group of eight of us that really enjoyed working together, but found it necessary to leave our current employment. In response the bank sent out from New York a partner (Bud Coyle) and a young Harvard MBA named Arthur Rock to meet with us.

While we had mutinied against our ill-tempered captain in the hope of saving our sinking ship, we didn't yet imagine ourselves as captains. We were completely surprised when Bud and Art suggested that perhaps we should strike out on our own rather than just look for another employer. We warmed to the idea of starting our own firm, because of the many advantages it held for us. We all owned houses in the area (something a lot cheaper to do back then). We knew that working for someone else would've meant moving and working for ourselves meant we could stay in sunny northern California. Hayden Stone agreed to take on the job of locating financing to start a company with the intention to pursue the goal that Shockley had abandoned: commercial silicon transistors.

Most people forget that this was before the days of organized venture capital. So we sat down with a copy of the Wall Street Journal and literally went through all of the companies on the New York

[20] This story is consistent with what others have written about the potential role for government expenditures. See for example the Bresnahan and Malerba internationally comparative study of the mainframe computer industry. (In *Sources of Industrial Leadership,* edited by Mowery and Nelson. 1999) 'Dumb' government money, readily available and not too closely targeted, may provide a useful early market for many technologies.

[21] Tilton's appendix notes that very few major semiconductor innovations can be traced to government R&D projects, and that at best we can speculate that these funds and projects expanded knowledge and capability in essentially unmeasurable ways in the firms that received them.

Stock Exchange trying to identify anyone we could think of that might want to start a semiconductor operation. The Hayden Stone team visited every one of the thirty-five we thought to be good prospects, and got turned down by every one of them. Not one even wanted to talk to our technical group. The reason, evidently, was because they didn't see how they could support an outside group while their own engineers doing similar things couldn't get the same kind of deal.

Then, quite by accident, Arthur and Bud ran into Sherman Fairchild, who was somewhat fanatical about new technologies. He introduced them to his successor chairman at Fairchild Camera and Instrument, and they agreed to take a shot supporting this new company. Each of the eight of us invested $500 in this start-up – a few weeks' salary. Fairchild put up some $1.3 million to get us going, and Fairchild Semiconductor Corporation was born. By design, Fairchild Semiconductor was to be an independent company for two years, and the Fairchild Camera and Instrument Corporation would then have the opportunity to buy us outright.

This new company eventually became the mother organization for several dozen new companies in Silicon Valley. Nearly all of the scores of companies that are or have been active in semiconductor technology can trace the technical lineage of their founders back to Fairchild.

At Fairchild we were mining an extremely rich vein of technology, but our little company was too small to handle all that we discovered. The net result was what I call the "Silicon Valley effect": every new idea that came along created at least one new company. Literally dozens of new companies came out of the Fairchild experience in just that first decade. Some we encouraged as a means of gaining a supplier, others we suffered as future competitors and drains on our resources. Some even became customers.

Not only did new technology come out of Fairchild, but the company also served as a successful example of entrepreneurship – the if-that-jerk-can-do-it-so-can-I syndrome. We were, after all, quite a young managerial team. (I was only 28 when we started Fairchild, and 39 when we started Intel.) It was a bit unusual at first to be the boss of your contemporaries, both for us and for them. We didn't have the traditional father-figure in a management role. We were all a little wet behind the ears, but making a go of it.

While we were learning on the job, by the late 1960s Fairchild Semiconductor had grown to be a $150 million business with 30,000 employees. But things had begun to deteriorate inside the company. For several years the semiconductor operation contributed more than 100% of the corporate profit. But our west coast tail was not very effective at wagging the east coast dog. Our parent company and owner, Fairchild Camera and Instrument, developed management problems. The board fired two chief executive officers within a six-month period, and was running the company with a three-man committee as the Board of Directors. This was not, we were sure, the right way to run a technology company.

It was clear the direction of the company was going to change. So when Bob Noyce (who was the logical internal candidate to become CEO of Fairchild Camera) saw that he would be passed over, he decided to leave. I felt that new management would probably be taking us in the wrong direction. I decided I'd rather leave before the changes than after. So, as before, the two of us set off to do something else.

While the catalyst for our Fairchild departure was the politics of internal control, the decision to leave Fairchild was motivated, in large part, by the fact that it had ceased to be the responsive and flexible firm we set out to build. As a result of our ignorance, we were sending our profits back to the parent company on the East Coast rather than asking to reinvest them in expanding Fairchild Semiconductor more rapidly. Ultimately, however, it's not clear that we could have expanded a lot more rapidly even if we had tried. There were just too many demands on the management team.

Oddly, I wasn't concerned about leaving a stable and well-paid job at Fairchild. Changing jobs in our industry had become fairly common and I was sure if this didn't work I could find something else to do. I didn't consider it much of a risk. We had watched many depart from Fairchild before us, and watched many of them succeed. Even those that failed at first often found success a second time around.

So wide open was the technology at that time that the much harder task was learning to recognize and manage the size of the opportunities we faced. For instance, I think my single biggest mistake at Fairchild was not appreciating how big the business for integrated circuits could be. As a result, we didn't take all of the steps we could have to grow to get the maximum portion of it. We kept looking for new things to do rather than really heavily investing in the areas we were in. It was hard to envision a market growing by ten or a hundred fold over a few decades, but that is exactly what happened for integrated circuits.

The great irony in our inability to recognize the size of this opportunity was that we had made great efforts at generating demand. Building these markets had a great deal to do with our projected productivity improvements, and recognizing that we had to provide a product to the market at a price that would overcome market reluctance to adopt new technology and generate demand. This was a lesson we learned at Fairchild when the integrated circuit market was slow to develop at first for a variety of reasons. The first ICs were fairly expensive, because the manufacturing yields were low in those days. That tended to restrict their application to where other attributes such as small size and weight were critical, significantly limiting the early non-military market. But even the military contractors failed to embrace ICs, citing several arguments against using them. For example, their reliability engineers were accustomed to measuring transistors, resistors, and capacitors separately. They would measure a resistor and see just how much it drifted and determine its reliability; they would look at a transistor to see how its characteristics held up electrically, etc. With an integrated circuit, they couldn't measure the reliability of these individual components and so they refused to use it. That was when Bob Noyce made a contribution to the integrated circuit so major it was second only to his invention of it: he offered to sell them for less than our customers would pay to buy the transistors and build the circuit themselves. But this was less than half of our current costs! Of course, when ICs became the cheapest way to do things, the military engineers, and everyone else, found that they could use them. Therein was the key to Bob's innovation.

Putting the price of an IC below the price of the individual components and also below our current cost of production simultaneously foresaw the necessary trajectory of our productivity (with the faith that we could get there technologically) and stimulated the market so that we would have demand enough to operate profitably. This was a number of fundamental steps forward for the semiconductor business all at once. Before that market change, ICs weren't developing into a business. We introduced the integrated circuit in 1961, and it was 1963 or later before we were really making money on them. Two years was a long time to look forward. But Noyce was one willing to take that significant, albeit highly successful, risk. The idea of lowering the product price to stimulate an elastic market for electronics has become a standard tactic of our industry.

Most of us working in the laboratory at the time of the completion of the first family of ICs did not realize at first that we had barely scratched the surface of a technology that would be so important. It was just another product completed, leaving us looking around for a new device to make, wondering, 'What's next?' So sure were we of the general usefulness of semiconductor technologies, we hadn't seen that some of the things we could build had similar general applicability.

Our ability to foresee what was happening in the industry outside of our specific technology and products was not any better. We anticipated industry consolidation rather than continuing fragmentation, so we focused on established competitors rather than the rash of start-ups. For this reason we tended to patent relatively few things, typically only patenting innovations which we thought we could police most easily and were the most difficult to get around. We patented only to be able to trade intellectual property with our competitors. Our lack of foresight led us to neglect some ideas that later became important. I was responsible for many of these oversights. For instance, in the early days of the integrated circuit, Bob Norman, who headed Fairchild's circuit design group, suggested the idea of semiconductor memory – that semiconductor flip-flops could be used as a memory structure. I decided it was so economically ridiculous, it didn't make any sense to file a patent. A few years later, of course, semiconductor memory was the first product area for Intel.

When we began to develop Ted Hoff's idea for the microprocessor about a year after Intel's founding, most important for our success was that Ted saw that this product had much broader applications than just the calculator contract we were designing the chips for. I remember him telling me from the beginning how we could use it to control anything from elevators to traffic lights. To me that was the greatest attraction because it was a general-purpose product again. It was a perfect example of what we were looking to build, a complex circuit that one could produce in large volume for use in a lot of different applications.

But even markets for generally useful intermediate products had to be broadened by deliberate action. For instance, at the time the first microprocessors were shipped, the total annual market for computers in the world was something like 10,000 units. The microprocessor would have been a commercial disaster if all we did was to replace those 10,000 units with cheaper processors. I remember going to a conference and speaking before a group that was more involved in applications than devices and explaining to them that we had to ask big questions, like, ' How are we going to develop markets that can use 100,000 of these a month?' (While one hundred thousand a month doesn't seem like many now when compared to the tens of millions shipped currently, it sure did then.) Ted's insight and the Fairchild experience with ICs helped us understand that this product had countless uses, but we also understood our efforts alone would build *volume* markets.

We set about aggressively seeking the placement of our processors in every kind of electronic device imaginable, combining extensive marketing with a strong and successful sales push for these 'design wins.' Still, in spite of our significant market-building efforts, and despite the keen eye we developed for the general usefulness of the products, we failed to anticipate the development of some remarkable high-volume markets. In the mid-1970s we still had no idea of the impact the microprocessor would have, and if anybody else in this business did they kept it to themselves. I recall one of our Intel engineers came in with the idea that using a microprocessor you could build a home computer. I asked him what it was good for, and the only application he could offer was that a housewife could put her recipes on it. I could just imagine my wife Betty sitting there with a computer by the stove. It didn't really seem very practical. In fact, when Steve Jobs came over to show us what was going on at Apple, I viewed it as just one more of the hundreds of applications that existed for microprocessors, and didn't appreciate that it was a significant new direction.

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Our Discussion:

Whereas the first two lessons were about the changing dynamic within the firm, this lesson and the next are primarily about the external activities of the firm and its interactions with the market. In contrast to the last lesson which stressed the importance of commercial orientation *within* the firm, this lesson describes the process of learning to function in the commercial marketplace in new ways.

Market-building

In this lesson there are as many failures to seize opportunity as there are successes at creating them. Fairchild and Intel repeatedly failed to recognize the markets as they emerged, to allocate enough resources to seize the markets they built, or even to anticipate the market value of their innovations. The fact that incredible success followed in spite of these missed opportunities is testament not only to the impressive numbers of opportunities revealed, but to the success they found in building markets.

In addition to learning the important lessons of marketing already known to other types of industries, Fairchild made the profound leap forward of peering down their cost curve and understanding the price elasticity of demand for their product. So much more than simply mass producing for a mass market, this is a discovery of the convergence between supply and demand (and their changing nature over the life cycle of a technology product) that fundamentally transformed technology markets.[22] Combined these market-building activities highlight the active role that successful firms play in the adoption of new technologies.

Lesson IV: Spin-offs and Limiting the Dimensions of Competition

The Story:

We found at Fairchild that a company active on the forefront of semiconductor technology uncovered far more opportunities than it is in a position to pursue. When people are enthusiastic about a particular opportunity but are not allowed to pursue it, they become potential entrepreneurs. As we have seen over the past few years, when these potential entrepreneurs are backed by a plentiful source of venture capital there is a burst of new enterprise. The example set by successful new enterprises, especially those started by people considered less capable or less deserving of success than those who

[22] It is perhaps also indicative of the uniqueness of semiconductor technology, as the cost of its basic product, the transistor, has declined by some hundred million fold since the founding of Fairchild Semiconductor Corporation in the late 1950's.

created the new idea, accelerates the process. Another important feature of the developing culture of Silicon Valley was the lack of stigma associated with failure in a venture. The entrepreneur did not risk his whole career in undertaking a start-up. Even a failed venture could make the engineer more valuable to a new company. More important than any “cultural” inclination or friendliness to new ventures, these are the origins of spin-offs and start-ups in a high technology environment.

Ultimately, both the advantage and the challenge of a start-up company is the ability to focus all energies on realizing the commercial possibilities of whatever product the company sees as important. Any established company has other things to maintain and can only devote a small portion of total available energy to a particular new enterprise. This lack of focus does not usually exist in a start-up. There are no distractions from existing product lines. Often, a start-up will have a much more powerfully capable team focused in an area than a big company can muster, as a larger company has many other positions in which it will want to employ its better people. Start-ups can also take more risk than can an established firm. There is no reputation to protect. This can speed products to market without all the precautions taken by the bigger, better-established firm. Running with the ideas that big companies can only lope along with has come to be the acknowledged role of the spin-off or start-up. Note the important distinction here between exploitation and creation: It is often said that start-ups are better at creating new things. They are not, and generally do not. Start-ups are best at exploiting under-utilized ideas.

One of the reasons that Intel has been so successful is that we have tried to focus R&D, thus maximizing our R&D yield and minimizing costly spin-offs. But successful start-ups almost always begin with an idea that has ripened in the research organization of a large company (or university). This is a fundamental tension between what is ideal for the individual technology firm, and the phenomenon that builds a dynamic high-technology region. Over time, any geographic region without larger companies at the technology frontier, or sizeable research organizations (either privately, within firms or within academia) will probably have fewer companies starting-up or spinning off, both because of lack of technically trained people and a shortage of ideas.

I think one crucial lesson we learned after Fairchild was that businesses at the cutting edge of technology, like people, can only move forcefully in so many directions at once. They are prone to distraction. As we learned this, we learned to limit the dimensions on which we competed. First, at Fairchild, we began to encourage and support spin-offs that could provide us with necessary components to our research and manufacturing processes. Later, Intel adopted an outright technology policy that we would make none of our own manufacturing equipment. We knew we couldn’t keep up with too many technologies, or dedicate the resources to be at the leading edge in all areas simultaneously.

Limiting the dimensions of competition can be a double-edged sword, however, since competition will heat up. In 1965, Electronics magazine's 35th anniversary edition editor asked me to predict the course of component technology for the next ten years. I looked at what we had done in integrated circuits, which then were about four years old. We had just gotten some of the first simple families out, and were trying to make more complex circuit in the lab. I looked at what was coming in the pipeline and saw that the number of elements in an integrated circuit was doubling every year. I simply predicted that what was happening was going to continue happening for the next ten years. Integrated circuits would therefore be a thousand times as complex in 1975 as they were in 1965, increasing from about 60 elements to 60,000. My thesis was that integrated circuits were going to make digital electronics dramatically cheaper by integrating much more on a chip, not to predict exactly the complexity. But amazingly, we stayed almost exactly on that curve for ten years.

While the rough accuracy of this prediction (even to this day!) has continued to astonish even me, the precision wasn't important for the arguments I was trying to make. In one respect this prediction it has become a self-fulfilling prophecy. Companies knew they had to stay on that curve to remain competitive, so they put in the effort to make it happen. In my view, this was the best thing I ever did for the Japanese semiconductor industry. Once they understood the technological progression in DRAMs – one kilobit, four, 16, 64 – they could multiply by four as well as any of us. Then, for the first time, they really had a fix on where the industry was going. Before that, the industry seemed to move in more or less random directions, which didn't work well in the Japanese consensus corporate culture. But once they had a roadmap of where the industry was going, they became very formidable competitors.

Even now, the Semiconductor Industry Association publishes road maps projecting the exponential changes in industry technology. As a result, companies know how far their products must evolve to remain competitive. The roadmaps help coordinate the constituent parts of this large disaggregated industry. With the signposts in place, we can be fairly sure that the required research and equipment development needed by the industry is done by the time it is needed, and each industry participant knows that to do anything less is to fall behind. These signals have coordinated expectations, bringing some predictability to product competition as well as to demand. The end result is faster innovation coupled with stiffer competition and less risk from uncertainty.

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Our Discussion:

Two facts exposed in this lesson imply a number of inter-related lessons for all technology regions. Fact#1: Unlike larger companies, start-ups can be better in specific domains because they can be more focused. Fact#2: A firm in a fecund technology will find more opportunities than any firm could exploit. Large firms in new technologies are therefore repositories of unexploited ideas. Restated another way, big firms have natural diseconomies of scope that a cluster of start-ups does not. Therefore, start-ups will prosper in areas where there are also large active high-tech firms.

It is often believed that simply promoting the establishment of smaller high-tech firms can create areas similar to Silicon Valley.[23] Focus on only new smaller ventures misses system nature of this kind of regional economy. A key feature of Silicon Valley has been its mix of both small and large high-tech companies. Just as 'Fairchild the start-up' represented a new mode of firm building, 'Fairchild the semiconductor giant' represented a new source of firm-formation, as it begat most of the semiconductor firms in Silicon Valley. Noting that Silicon Valley has been a positive place for new firm formation, many observers make the mistake of understanding spin-offs and spillouts only from the perspective of the new venture, and not recognizing an essential element of conflict in these firm formations. Large firms struggle against spin-offs. Spin-offs are often costly in terms of market share and human-capital. A spin-off is not always (perhaps not often) a net positive for the established firm. Most established firms, Intel and other Silicon Valley firms included, would squelch most spin-offs if they could. The system that has evolved here did not come about because Silicon Valley firms large and small got together and developed an efficient "engine" for firm formation and growth. On the contrary, this system exists because those who would stop spin-offs cannot. This system of spin-outs and start-ups, so fundamental part of the Silicon Valley economy, was and continues to be fundamentally contingent on the fecundity of the opportunities pursued here.

The nature of a wide-open technology space, however, is that even a well-run large company cannot be at the forefront in all the leading, inter-related technologies. Such was the case in semiconductors. At times helpless to prevent unwanted spin-offs, Fairchild also figured out that it was more efficient to shed some technologies and products in the form of spin-offs. The importance of this firm level discovery to the structure of this valley is best understood in the context of Intel's policy of spinning off its equipment suppliers, and more generally of not buying internally produced equipment. This decision created a vertically specialized industrial organization, and greatly proliferated competition and innovation in numerous complementary technologies. By understanding the boundaries of what they could do best, they avoided excess diversification and inefficiency. Actively spinning off these parts of the business is a way of gaining the advantage of these other technological endeavors without having to bear the related costs and risks of internal coordination.

The course of action limiting the scope and dimensions upon which they were competing is counter to the inclinations of most industries. Elsewhere it is generally assumed that letting go of control of adjunct technologies - i.e. spinning off complementors as Intel did actively -is risky in that your supplier becomes the ally of your competition.

At Intel this practice represented the viewpoint of a longer time horizon. Limiting the technologies developed within the firm was more about averting the risk of falling behind in the fast moving complementary technologies, and exhibiting confidence in the company's core competency. In semiconductors, with so many adjunct technologies, it was obviously unreasonable to expect to win in every technology. In fact, with so many changing technologies, the firm has no choice about whether there will be spin-offs, since they cannot afford to dedicate the resources to keep up in technologies that they only infrequently upgrade in the manufacturing process. But if it manages its opportunity well, the firm can have some choice on which technologies escape. This allows the well-managed firm to focus in its competitive advantage.

Lesson V: Luck on a Clean Slate

The Story:

I never fail to credit the element of luck.

My personal success stems in part from the fact that Fairchild's timing and direction were extremely fortuitous. Semiconductor science and technology were evolving rapidly. Fairchild invented the planar technology that provided the basis for the integrated circuit. Intel made a lucky choice of a new version of the MOS technology using a silicon layer for the gate of the transistors. This approach offered several advantages over the existing approaches, but required that some fairly complex processes be developed. These were sufficiently difficult that it took Intel engineers, with the focus a start-up has, nearly a year to make them work. The established semiconductor companies took several more years to recognize the benefits of silicon-gate technology and follow along.

The luck of this valley stems from the fact that it began with a fairly clean slate in a wide-open technology space. Silicon Valley's evolution was closely tied to the fact that semiconductor firms did not try to vertically integrate into manufacturing equipment, supply parts, and materials. It was simply fundamental that this was an area of rapid technological growth at all levels of the supply chain.

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Many components of the genesis of Silicon Valley flowed naturally from the existence of our large technological opportunity. As an example, venture capital is often the focus of attempts to recreate Silicon Valley. Venture capital partnerships really started in Silicon Valley about three years after Fairchild was born. In the early stages existing corporations financed many of the Fairchild spin-offs. By the time we found ourselves leaving Fairchild to begin again, the venture capital industry had grown in leaps and bounds.

When we founded Intel, Bob Noyce called Arthur Rock and said, "We are setting up a new company. Would you help us raise the money?" Arthur said "sure," and that was the commitment of our first round financing. We wrote a single page business plan. It was very general, simply saying that we were going to work with silicon; we were going to do diffusion and similar processes to make interesting products. That ease of that transaction reflected both the increased supply of funds and the confidence our reputations had earned us. But it also reflected changes wrought by our experience and experience of our investors, and the natural growth of the industry out of the opportunities that arose here.

Rock and others who had come to invest in semiconductors had met with success and found that potential investment opportunities abounded. The venture capital industry *followed* semiconductor and other high-technology investment opportunities, and built a local industry out of their success. When Intel was founded, we weren't requesting loans from old-style bankers or corporations operating in other businesses, but from technically knowledgeable people who had left the manufacturing line to be at capitalism's front lines.

Plus we had learned a lot at Fairchild. We had made mistakes and had ideas how many of them could be avoided when starting all over again. In a very real sense Intel was the third start-up for Bob Noyce and me. We had been the seventeenth and eighteenth employees at Shockley and had been there from the beginning at Fairchild. It was our good fortune to start over with a clean slate once again.

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Discussion and Conclusion

Luck played a role in nearly every component of this story of semiconductors in and the birth of Silicon Valley. The success of any particular firm such as Fairchild had a large component of luck, stemming in part from the luck of picking the right technology, and the right approach, at the right time. At the regional level, some luck of Silicon Valley can be duplicated. It was luck and learning combined that led to a disaggregated industry structure. Firm and regional policies that encourage competition and disaggregation (in the right technologies), can be an important part of dynamic growth. And some luck cannot be duplicated. No one could foresee the exploding demand for these products that arose from the fortuitous development of computing and business information processing in the same decade. But examining the role luck has played highlights the progressive nature of this early history. Silicon Valley came to be because the scientists and engineers in this place responded in the best way possible to a fortuitous and unpredictable technological opportunity. These opportunities attracted venture capital, and led them to stay.

General Growth Factors vs. Regional Growth Factors

It should be clear that luck played a role both as a factor of general growth, and as a factor leading to agglomeration economies and the birth of a high-growth, technology-based, regional economy. Most of the factors we have discussed belong in one or both of these categories, if in different ways. For example, the evolution of scientist-managers is a general factor in growth nation- and world-wide. The fact that so many scientists learned about management at Fairchild, in semiconductors, in one brief span of time was important to building both the human capital and (business-)cultural expectations that have been regional growth factors. The process of learning to manage science and scientific discovery for commercial aims is a factor in all growth. Likewise, the training and scientific exploration performed by universities is a transportable and valuable general growth factor. The existence of available investment funds and encouraging tax structures are factors in general growth; the presence of a number of opportunities in one place that lead to the development of a risk-investment industry is an important regional growth factor.

Risk and Reward

As important as the role of luck, indeed perhaps formative of it, is the risk-taking and hard work that built the companies at the core of this regional economy. In the mythic Silicon Valley of more recent times, the centrality of hard work, risk and luck often get lost. In our celebration of the 'magic' of this local economy, we lost sight of the importance of the work of creating transforming technology into useful products. California's dot-com Gold Rush saw the growing expectation of personal fortunes built on a year's work or two.

The un-mythologized Silicon Valley-style economy has big opportunities and uncertain technological requirements inducing smart people to take big risks. Their success grows from the combination of a bit of luck, and the tremendous hard work and sustained investment in market-building and firm building.

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