ONE

Introduction

Timothy Bresnahan and Alfonso Gambardella

Clusters of high-tech industry, such as Silicon Valley, have received a great deal of attention from scholars and in the public policy arena. National economic growth can be fueled by development of such clusters. In the United States the long boom of the 1980s and 1990s was largely driven by growth in the information technology industries in a few regional clusters. Innovation and entrepreneurship can be supported by a number of mechanisms operating within a cluster, such as easy access to capital, knowledge about technology and markets, and collaborators. This generates a higher rate of technical progress and one more attuned to market needs. These clear benefits have drawn scholarly, business, and government interest to industrial clusters.

Established clusters of high-tech industry, such as the Silicon Valley of today, have a number of well-documented advantages for innovation. Entrepreneurs find access to capital easier in a cluster, and venture capitalists and investment bankers find it easier to locate new investment opportunities. Universities with strong technical research capabilities, such as Stanford and Berkeley in Silicon Valley, are closely linked to commercial activities. Firms in a cluster participate in thick markets for technical labor, managers, and other inputs. Information about new technical and market opportunities flows through a cluster's institutions and through its informal networks very rapidly. Many of these benefits arise by capturing external economies, lowering the costs of invention and growth at large scale. Silicon Valley is an example of exploitation of this virtuous cycle, with multiple new inventions commercialized throughout the United States and exported worldwide. The result is substantial producer rents for firms in the cluster and effective invention for growth.

The successful exploitation of a virtuous cycle by existing established clusters leaves questions about the potential contributions of new clusters unanswered. What are the preconditions, in the region where a new cluster might form, for an effective supply of innovation? What causal mechanisms push the region into takeoff in a virtuous cycle? An important part of our argument is that simply looking at Silicon Valley in its mature phase cannot tell us much about the *pre*conditions or casual mechanisms. Indeed, looking at successful clusters has led many analysts to a kind of "recipe" approach. "Take one great university, sprinkle with liberal doses of venture capital, mix in an entrepreneurial culture," and start the virtuous cycle. Because this approach skips over any empirical examination of clusters during their formation stages, we reject it in favor of an approach that uses a detailed examination to guide analysis of the preconditions and the causal mechanisms in the formation of a cluster.

The mission of this book is to analyze systematically the differing attempts to gain national economic advantage from regional clusters of development in information and communications technologies (ICT). We have sought to avoid both the hagiographic "Silicon Valley is great" mode and the hypercritical "there are no external economies" mode. The real questions surround the sources of long-run economic growth in clusters of industrial activity. We define a regional cluster simply as a spatial and sectoral concentration of firms; and we measure success by the ability of the cluster as a whole to grow, typically through the expansion of entrepreneurial startups.

We set out to answer the fundamental questions about how clusters are formed. Our research design selected places with nascent clusters in ICT industries. One of these is Silicon Valley, which we examine during its takeoff as a center of the integrated circuit industry decades ago. The others are worldwide regional clusters during the Internet era. Our goal was to understand the formation of new technology clusters deeply enough to address both the issue of uniqueness and the issue of policy. The main places we study achieved significant growth based on entrepreneurship at a takeoff stage. For Silicon Valley, that was decades ago, but for the other clusters we study, far more recently. Our purpose in looking at a number of related early-stage successes was to drive our research deeper than the "recipe" level. We are attempting to learn the deep similarities across places that, on the surface, look quite different.

In particular, we look in detail at Ireland, Israel, Scandinavia, India, and Taiwan in the late 1990s in comparison with Santa Clara County (Silicon Valley) in the 1960s. Many of these are, despite their significant

differences, prototypical cases of nascent clusters. They have all exhibited a significant acceleration in the production of ICT during the 1990s. Their ICT growth has been exceptional according to practically all major indicators: annual double-digit growth in the number of new firms, in ICT revenues and employment, and in exports; and an increasing share of ICT in total exports of the region (up to one-third of total exports in the case of Israel). Not enough time has gone by to discover whether any or all of the new nascent clusters will see the sustained success and contributions of Silicon Valley, but now is a good time to examine them in the startup stage.

We make no effort to offer a comprehensive view of the world's high-tech clusters today. Far too many areas have labeled themselves as high-tech clusters, and it would be a long and dull slog to explain which of them have the label and little else. The positive feedback elements of a successful cluster also make it difficult to learn anything from clusters that don't take off; an implication of "nothing succeeds like success" is that "nothing fails like failure." Accordingly, we stayed within the tight criteria just described. As a result, we have picked cases related to the ICT industries, but for the 1990s this overlaps with the criterion of double-digit growth.

Some may think that our agenda is to glorify a U.S. colonialist view about the new processes of ICT-led growth. After all, the oldest and most successful cluster we examine is located in the United States, and most of the other regions we look at have U.S. linkages. Yet the analytical issues that these facts raise are hardly the ones that go with a colonialist agenda. First, we noted early on in our researches that the keys to cluster formation in the late 1990s involved efforts that would be very difficult to classify as "imitating Silicon Valley." Indeed, if we were to have attempted to research the many failed clusters, we would reproduce the familiar result that slavish imitation is a low-return activity.

The linkages to the United States appear to be related to a far more general point – namely, that openness and connection to demand are important for export-led growth. Within the computer- and Internet-oriented clusters we study, access to demand is easier for regions having linkages with key, established complementors located in the United States (and Silicon Valley in particular). However, we sought to understand the role of openness and export orientation separately from the U.S.-connection in our work. Here, choosing a Scandinavian cluster provided one (considerable) advantage because it grew in wireless telephony technologies where the external linkages were very much not to the United States, as that country adopted a go-it-alone technical strategy.

The research questions this raises are serious and important. Much of the analysis of clusters focuses on the supply side: agglomeration economies, the need for venture capital, the need for technically oriented entrepreneurs. Our research also asks the demand questions. Can this provide an explanation for how the regions we study flourished? Certainly they are not the strongest in the world in terms of technical capabilities (when compared with, e.g., the large nations of continental Europe or with Japan).

Early in our research we noticed several similarities among our selected places. From a regional economics perspective, these places were candidates for high-tech industrialization at the beginning of the period we study. They are all regions that had less high-tech employment than the education status of their labor force would suggest. They were all, in some sense, empty. Silicon Valley was located in the relatively rich United States, to be sure, but was itself an agricultural region far from the parts of the country where existing electronics industry supply occurred. This pattern of being something of an outsider locale before the cluster begins to form is repeated across all our regions.

The technologies that were taken up by our nascent clusters have broad similarities from a technological or market perspective, as well. All the clusters we examine were formed at times of substantial new technological opportunity in ICT. The integrated circuit was, we now know, a major revolution in the technical basis of many electronic devices. The Internet and other networks in the present provide, in parallel, a substantial opportunity for the founding of new industries and the creation of new markets. At both times, the new technology areas were, at least in the short run, in a relationship of complementarity with preexisting electronics technologies from preexisting firms. The mid 1960s and the late 1990s were good times to be in the ICT investment business, and clusters that were affiliated with new, and substantial, technological opportunities have better chances. We consider the possibility that the expansion of the geographical basis of supply in ICT is linked to the expansion of its technological basis, as new cluster formation is contingent on avoiding direct competition with existing suppliers, perhaps even linked to complementarity with them.

Despite these broad similarities, very important practical differences exist among the regions we study. Some are in rich countries with a stable record of capitalist development, established capital markets, and so on. Others, like the parts of India we study, are small corners of far poorer countries. Taiwan and Ireland were each in a period of general economic

growth. The regions we examine are embedded in a very wide range of national economic systems and national innovation systems.

The similarities and differences across these regions' technologies will lead us away from the "recipe" vision of the formation of a cluster and permit an investigation of the fundamental requirements behind a cluster. All of the technologies in which these regions grew are in ICT, yet they, too, vary widely, from integrated circuits to software and networks to wireless phones. That, too, will play a role in our analysis. The research design goal was to look at places and times similar enough to permit meaningful comparison but different enough to provide meaningful contrast.

We spend less time contrasting these early-stage successes with less successful regions, such as the numerous failed government-sponsored imitation Silicon Valleys, for a number of reasons. The most important of these is our goal. The contrast with places where the virtuous cycle has not started, despite efforts to get it going, inevitably leads to the finding that such places lack many of the elements of the successful Silicon Valley. We make, however, two important exceptions. First, we look at one European "near miss," Cambridge. Although Cambridge has had considerable success in generating entrepreneurship, it has not matched the patterns, and particularly the growth figures, of the other regions that we have surveyed. That contrast, we hope, will illuminate some of the inner workings of the cluster formation model.

Second, we examine the rest of the United States in contrast to Silicon Valley. Our overall research design took seriously the proposition that government policy leading and directing cluster formation might be an important part of the cluster formation story, although we ultimately reject that proposition. The only way to rescue that proposition is to show that the failure of government-directed cluster formation is a particularly European or Asian phenomenon. Accordingly, we examine the U.S. regional policy experience, in which various state and local governments have attempted to lead new cluster formation. Relatedly, to understand the contrast between national innovation systems and regional ones, we look at venture-capital-financed growth in a number of U.S. clusters outside Silicon Valley.

It is essential to attack this analytically. The Silicon Valley experience tells us both something general – that is, useful to guide policy today – and something specific about that place. Telling those apart involves, in the first instance, avoiding the trap of thoughtless imitation of past success. Instead of thinking of the problem as one of successful imitation of Silicon Valley, it is better to see the problem as one of explaining how

a cluster can be formed. In the first instance, that calls for considering the role of chance and the unpredictable as key mechanisms behind the location of new clusters. Certainly the large role of new technological opportunities in the successful clusters we study calls for a careful consideration of the importance of forces far beyond the control of firms, regional governments, or national or regional innovation systems.

At a second level, the analytical approach calls for carefully distinguishing between the general and the specific. Here we gain much of the leverage of our similar-but-distinct research design. By looking at countries that are not the United States, we can examine the deep structure of cluster formation, rather than merely reporting the particular form that structure takes in the western United States. This leads us toward an analytical approach, in which we look for explanations that are partially particular to that region but whose general structure is laid clear.

The plan of the book begins with a series of chapters about the specific nascent clusters just named, then proceeds through some statistical analyses of the U.S. regional experience. Our concluding chapter builds on that foundation to attempt an answer to the fundamental questions about preconditions and causation. Reaching those questions by examining the preconditions for formation of new clusters and the mechanisms of new cluster formation is the ultimate mission of this book.

TWO

Learning the Silicon Valley Way

Gordon Moore and Kevin Davis

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. We have tried to capture what we feel are the crucial elements of the early history of Silicon Valley through the retelling and reexamination of the experiences of Shockley, Fairchild, and Intel.

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.

Gordon Moore is widely regarded as one of Silicon Valley's founding fathers. Moore returned to his native California in 1956 to work with Shockley Semiconductor. His membership in the "Traitorous Eight" who left to start Fairchild Semiconductor in 1958 places him at the top of most "genealogies" of Silicon Valley. Cofounder 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. *Eds.*

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 were the size and nature of the technological opportunity that induced it; more than government contracts, university advocacy, or sunny weather, the opportunity defined the creative response.

We hope that our reflections on my firm-level experience during the founding of Silicon Valley clarify how these changes took place and their central role in the establishment of the Silicon Valley–style economy. We offer, however, a caveat. Comparing this particular set of experiences 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 compose 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 those who started and built these companies and the lessons they learned in the technology business and its organization that were *necessary* for the region to develop a dynamic high-technology economy. In so doing, we also find ourselves questioning some preconditions often presented as crucial, which we feel were not. We present here a less all-encompassing, but more precise, historical analysis.

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 and analytical tomes that resemble recipes or magic potions, such as:

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 overemphasizes "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 equally flawed mode of constructing a 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 startup 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 startup mentality in this place; that a defining few of us (the so-called Traitorous Eight) "invented" startups 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 stem more from this incremental process of learning these particular lessons than from any one person, company, or organization. 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 existing historical analysis and policy questions. For clarity's sake, we have tried to group these lessons into five categories, coupling personal history 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 reflect our 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 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