Spinoffs and the ascension of Silicon Valley

Cristobal Cheyre,¹,* Jon Kowalski² and Francisco M Veloso³

¹School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile. e-mail: ccheyer@ing.puc.cl, ²McKinsey & Company, One Oxford Center, 301 Grant Street, Suite 2600, Pittsburgh, PA 15219-1414, USA. e-mail: jon@jokowalski.com and ³Católica-Lisbon School of Business and Economics, Universidade Católica Portuguesa, 1649-023 Lisbon, Portugal. e-mail: fveloso@ucp.pt

*Main author for correspondence.

Abstract
This article analyzes firm entry and performance in the semiconductor industry from the introduction of the integrated circuit (IC) in 1965 until 1987. During this period the industry, which was initially concentrated on the east coast of the United States, became increasingly clustered in Silicon Valley (SV), California. This location shift was accompanied by a change in the technology used to produce semiconductor devices. By studying how diversifiers and new firms enter into IC production, and the technology they choose to produce ICs, we document the process of growth of SV. In particular, we analyze how agglomeration economies, as well as the heritage of new firms’ founders affect the opportunities pursued by entrants and their long-term likelihood of success. We find that IC entrants in SV were more likely to enter at the technological frontier than IC entrants in other clusters. However, we find no evidence suggesting that being located in a cluster helped existing IC producers that were not initially at the technological frontier to catch up with the rest of the industry. Examining long-term performance, we find that firms that become top producers are disproportionately spinoffs of leading firms or diversifiers with a transistor background. While most of these firms were located in SV, after controlling for heritage and background, location has no significance on the likelihood of becoming a top producer.

JEL classification: R11, L26, L63

1. Introduction
Silicon Valley (SV) is synonymous with innovation and high-technology firms. This reputation is certainly warranted, with at least one-third of the nation’s venture capital pool historically awarded to firms located there, more than 50% of all public technology companies headquartered in the region in 1980, and 39 of the 100 fastest growing companies during the 1990s based there (Saxenian, 1994). The prominence of SV, however, did not start with the industries for which it is known today, which include computer hardware and software, among others. Rather, the silicon in the region’s moniker refers to the material used to produce semiconductor products, the first global industry based in the region.

There is a profusion of research looking at the benefits of the technological cluster that was established in SV. Yet, there is surprisingly little information about the initial stages of the process that led SV to become the most successful example of a cluster. This is particularly intriguing because semiconductors, the industry that gave birth to
SV, originated and initially developed very far from there. The industry was born at Bell Labs, and was initially picked up by a number of electronics producers that were mainly located in the east coast. The first relevant players were producers of vacuum tubes that diversified to producing primitive versions of transistors made with germanium. None of the initial leaders in the industry were located in SV. Instead, they concentrated in Boston, New York, and Los Angeles, the cities that hosted the leading producers of vacuum tubes and electronics (Klepper, 2009).

By contrast, newer and more advanced versions of transistors were all introduced by new firms, mostly located in the west coast, especially around San Francisco. These newer transistors employed a completely different topology and material: they were made of silicon and constructed using the “planar process.” The evolution that followed is particularly interesting, as the industry kept evolving into more complex devices, specifically integrated circuits (ICs), and the relation of forces between early and late entrants into transistors shifted. As silicon transistors and the planar process turned into the basic building block of ICs, east coast producers of early semiconductor devices faded, and the industry effectively shifted location to the region around SV, with the exception of a couple of very relevant firms that developed outside this region.

In this article, we carefully document the process of firm entry and growth that led to the emergence and preeminence of the semiconductor industry in SV, and test a number of hypotheses that evaluate the importance of co-location and pre-entry experience in the growth of firms and clusters. The novelty of this work is that we simultaneously evaluate both the role of co-location and pre-entry experience by taking advantage of two important changes that occurred in the foundational years of the industry: the change in locus of the industry from the east coast to the west coast, and the technological advances that made complex IC devices possible. This analysis is enabled by the collection of detailed information on a rather complete set of potential diversifiers, and of all significant entrants into semiconductors, along with information on their founders and their work experiences, as well as data on the entrants’ production and top sales status throughout the period of study.

Our theoretical analysis is based on two theories that have proven relevant for the evolution of the semiconductor industry. The success of SV has been traditionally explained using the precepts of agglomeration economies. The idea behind this theory dates back to Alfred Marshall (1890) and states that co-located firms benefit from lower transportation costs, labor market pooling, and knowledge spillovers. A number of case studies on SV provide evidence supporting that these benefits were at play. There are many accounts of informal exchange of information (Bassett, 2002), and well-documented evidence of a very active labor market (Saxenian, 1994). The other factor that was very relevant in the evolution of SV is the number of spinoffs that formed there. Thus, our analysis is also grounded in a growing literature on intra-industry spinoffs1 that we call “heritage theory.” Specifically, we consider how the accumulated capabilities and heritage of new firms’ founders affect the initial opportunities pursued by these firms, their likelihood of success, and the establishment of a cluster. Spinoffs are important because they have been shown to outperform other entrants and surpass incumbents across different industries (Agarwal et al., 2004; Bhide, 2000; Franco and Filson, 2006; Klepper, 2001). Moreover, the spinoff generation process may also have important consequences for the emergence of a cluster. Spinoffs performing cutting-edge work and looking to leverage their connection with their parents prefer to locate in their proximity (Berchicci et al., 2011). If early leaders generate spinoffs that become leading firms, and these spinoffs generate even more spinoffs, this process can lead to emergence of a cluster (Buenstorf and Klepper, 2009).

Observing the location and technological decisions made by entrants and existing producers allow us to distinguish the influence of agglomeration and heritage. While both mechanisms can be at play simultaneously and lead to similar outcomes, there are some telltale signs that signal which of the two were more important in different events within the industry. For example, while agglomeration benefits all co-located firms, the influence of heritage is firm specific.

Our results highlight the importance of both heritage and location, albeit the importance of each of these factors changes over the tenure of firms. Both heritage and location greatly influence new firms. Entrants located in SV, including spinoffs of monolithic IC producers and diversifiers with experience in transistors, were more likely to enter IC production at the technological frontier. However, in the long term, spinoffs outperform all other entrants, even those that were located in SV and entered using the leading technology. Moreover, IC firms located in SV that were initially using other technologies did not appear to have an advantage shifting into the dominant technology.

1 We define spinoffs as firms founded by previous employees of incumbents in the same industry.
The article is organized as follows. In the next section, we review the early stages of the evolution of semiconductor industry, including its regional distribution, and detail the important influence that Bell Labs had in the process. In the following section, we develop a set of hypothesis on entry and performance for the semiconductor industry, exploring in particular the role of the regional and pre-experience dimension. Next, we present the data, followed by an empirical analysis where we test the established hypothesis. Finally, we discuss competing explanations for our findings and speculate on the implications for the development and economic impact of industry clusters and intra-industry spinoffs.

2. Firm entry, technological change, and the location of the semiconductor industry

The invention of the transistor at Bell Labs in 1947 can be singled out as the event that gave birth to the modern semiconductor industry. While commercially available transistors were available shortly after, the electronics industry producing radios and televisions (TVs) favored vacuum tubes well into the 1950s (Braun and Macdonald, 1982). The development of semiconductor devices was greatly influenced by the military because of the inadequacy of vacuum tubes to detect radar waves, which was of particular importance for the US government during World War II (Braun and Macdonald, 1982). Bell Labs was a key player in developing a better understanding of the nature of semiconductors, and ultimately for the public demonstration of the point contact transistor in New York in 1947 (Morris, 1990: 27).

Throughout this period, semiconductor manufacturing was primarily clustered in three regions: New York City, Boston, and Los Angeles (Klepper, 2009). Firm data presented in Figure 1 shows that during the early years of the industry, the region of New York City dominated over the other regions with respect to the number of transistor producers. Over time the concentration of producers in the remaining three major regions, along with SV, grew and converged to between 10% and 20%. The initial importance of the New York area is not surprising given the role that Bell Labs played in the early evolution of the industry. The firm invented the transistor and continued to move the state of the art forward. Moreover, due to antitrust considerations, Bell actively disseminated information regarding transistor production. It liberally licensed its patent to any firm willing to pay an upfront fee of $25,000, held multiple symposia to educate other firms on transistor technology, and worked with firms across the country to help them become capable of designing and producing transistors (Holbrook et al., 2000).

This peculiar situation, which is very unlikely in competitive industries, contributed to the reinforcement of the clusters where most electronics firms were based. As a result, many of the early leaders in transistors were producers of vacuum tubes and electronics located close to Bell Labs or in one of the remaining industry clusters (Klepper, 2009), which entered the production of germanium junction type transistors based on information licensed by Bell Labs. These firms included General Electric, RCA, Raytheon, and Sylvania. The influence of Bell openness policy on developing an ecosystem of firms working around its transistor knowledge did not stop at broad licensing due to antitrust pressures. Bell realized that transistors were complex devices, and that it was necessary to have many firms involved to push the technological frontier (Tilton, 1971: 75–76). Thus, the organization routinely included cross-licensing clauses in its licensing agreements.

The first germanium transistors were rather crude and unreliable. With the efforts of Bell and other firms, transistors’ performance increased significantly. The grown junction transistor developed by Gordon Teal at Bell Labs in 1951 was less noisy and easier to produce than its predecessors, but still suffered from several limitations. In particular, it would not operate at high frequency and temperature (Moore, 1998: 36), something that was critical for several important applications, in particular military applications. This problem was only solved with the invention of the diffused junction transistor (Reid, 2001). The first mass-produced diffused transistor was the mesa transistor (named for its mesa-like shape) developed at Fairchild, a firm founded in 1957 in San Jose, CA. This is a very significant event in the industry because it was a major innovation that was introduced in a region without any notable semiconductor production, and that used a different material: silicon.

2 The origin and nature of the data will be explained later in the article.
3 The number of transistor producers is less than 40 prior to 1959, meaning that the geographic concentrations vary wildly as the mix of producers changed each year. As a result, geographic concentrations are reported starting in 1959.
Despite its location in California, Fairchild had strong ties to Bell Labs. Its eight founders had previously worked at Shockley Semiconductor, the company that William Shockley, a Bell Lab’s scientist and inventor of the point contact transistor, founded in 1955 in his hometown, Palo Alto, CA. Shockley was very successful in hiring talented employees from the east coast (Moore, 1998: 53), but his poor management skills led many of them to leave. Fairchild’s founders recalled that the memos from Bell that Shockley had obtained regarding oxidation and other manufacturing processes played key roles in the development of semiconductor technology at Fairchild, specifically the diffusion and planar processes (Moore, 1998). While the first commercially available silicon-based diffused transistor was introduced in what is now known as SV, most of the knowledge used for its invention came directly from the east coast.

Although the improvements on transistor technology and manufacturing had greatly increased the reliability of these devices, and in turn devices that formerly used vacuum tubes, the increasing complexity of electronic systems required a different approach to achieve reliability. As electronic devices incorporated more and more discrete components and interconnections between them, the probability of failure increased with each additional connection (Reid, 2001: 16). The only way of solving this was to replace circuits with hundreds of different components by one integrated device, a path that one often referred to as miniaturization. We now know that the solution to this problem started with the almost simultaneous but independent invention of the IC by Fairchild and Texas Instruments (Reid, 2001: 115). Yet, during the 1950s there were many different paths being pursued with this objective, and the overall situation of the semiconductor industry can be described as uncertain, with many possible future trajectories (Holbrook, 1999).

Among the different alternatives pursued, three deserve special attention: Hybrid ICs, Film ICs, and Monolithic ICs. Hybrid ICs and Film ICs were closely related and were the most conservative options, as they used off-the-shelf component and techniques. Preexisting firms mostly advanced them as their response to the miniaturization problem. Initially they were the most cost-competitive types of miniature circuits, but as other technologies evolved, they became less relevant (Kowalski, 2012). The other approach was to produce Monolithic ICs, a completely different technique that consisted in forming all of the components of the circuit on a single semiconductor substrate. This approach was invented almost simultaneously and independently by Jack Kilby at Texas Instruments and Robert Noyce Fairchild Semiconductors. It marked a departure from the expertise of existing east coast producers, as its methods heavily borrowed from the techniques developed to produce silicon transistors. The most important technology for producing Monolithic ICs was the planar process, which was invented at Fairchild.

The process that followed is remarkable. SV kept growing after the invention of the IC in 1958, and the distribution of the industry changed markedly. SV’s share of producers grew rapidly, with the region achieving a share equivalent to Los Angeles and Boston in the early 1970s. This growth continued throughout the 1970s, with the
region overtaking New York City’s share by the early 1980s. By the late 1980s, SV had become the dominant region with respect to the share of semiconductor producers, accounting for just less than 30% of producers in the industry. The overall geographic distribution of semiconductor firms (including both transistor and IC firms) over time is shown in Figure 2. Comparing with Figure 1, which includes transistors only, it is evident that SV became the leading region following the introduction of ICs. While the number of transistor firms reaches a plateau in the 1980s (Figure 1), the proportion of semiconductor producers kept growing strong due to the entry of IC firms, many of which located in SV.

3. The development of a regional cluster

From the historical review presented in Section 2, it is evident that both geographical proximity and previous experience played relevant roles in the evolution of the semiconductor industry. This section develops a series of hypotheses to evaluate the role that of each of these mechanisms played in the conditions necessary for the formation of a regional cluster. It is important to note these are not necessarily competing hypotheses, as most likely both mechanisms were at play. Our aim is to determine how each mechanism contributed, and which ones seem to be more relevant for the long-term success of firms.

For a cluster to emerge there have to be mechanisms that allow for mass entry of new firms, for the relocation of firms located elsewhere, or for the massive growth of existing firms. Firms may relocate to clustered regions to benefit from agglomeration, namely, due to the concentration of skilled labor, the availability of specialized supplies, and the possibility of knowledge spillovers. The attractiveness of each of these factors will vary across industries (Alcácer and Chung, 2014). Considering that SV had none of the early leaders of the semiconductor industry, and that existing related industries were mostly clustered on the east coast, it is unreasonable to assume that many existing firms

---

4 While the semiconductor production data begin in 1949, the small number of producers in the first years of the industry produces somewhat erratic distribution data. Therefore, this figure shows the distribution of producers by region starting in 1959, which is the first year when the number of producers is at least 40. Additionally, this graphic includes all firms for which an entry and last production year are known.
located elsewhere would relocate there. Thus, the growth of a cluster in these conditions had to be fueled by the creation of new successful firms. The hypotheses developed in this section take advantage of the rich geographical and technological variation of the first years of the semiconductor industry to simultaneously test how agglomeration economies and the heritage of firms’ founders influenced entry, technologies adopted at entry, migration to new technologies by existing firms, and ultimately firms’ long-term success. Understanding the process by which new firms are created and the effect of their entry conditions in long-term success can help us understand how SV emerged and developed.

The theory of “Organizational Heritage” is based on the idea pointed out by Nelson and Winter (1982) that the memory of new firms comes from its organizational actors’ experiences. A new firm’s pre-entry resources and capabilities greatly influence the industry it will enter and its likelihood of success (Helfat and Lieberman, 2002). There are several ways by which a new firm may have significant pre-entry experience, but two types of entrants seem particularly relevant in the semiconductor industry: diversifying firms and spinoffs. Diversifiers are firms with significant experience, and whose capabilities can be adapted and redeployed in a new application within an industry or in a different industry. A number of studies have found that diversifying entrants with an applicable skillset perform better in a number of industries, including radio producers that diversified into the US TV receiver industry (Klepper and Simons, 2000) and security safes or computer producers that entered the US ATM manufacturing industry (Lane, 1988). Spinoffs are firms founded by individuals that decide to leave employment at incumbents to create their own firm in the same industry in a closely related field (Klepper and Sleeper, 2005; Cassiman and Ueda, 2006). Spinoffs have been shown to outperform incumbents in a number of industries (Agarwal et al., 2004; Bhide, 2000; Franco and Filson, 2006; Klepper, 2001). The quality and extent of the founder’s previously acquired skills account for differences across firms in terms of founding conditions and later performance (Agarwal et al., 2004; Franco and Filson, 2006).

Diversifying firms and spinoffs have in common the redeployment of previously acquired skills and capabilities in a related setting. In the case of spinoffs, the prior knowledge of founders is directly applicable in the new firm, and in the case of diversifiers the importance of prior experience varies significantly with the relatedness of the firm’s prior activities with the new opportunity being pursued. In an extensive survey of the literature, Helfat and Lieberman (2002) conclude that resources and capabilities at the time of entry greatly influence the field a firm enters and its long-term likelihood of success. They hypothesize that potential entrants base their decision to enter a particular industry and the timing of their entry on the match between their pre-entry resources and capabilities and the resources profile required in the new industry. The resource profile necessary to enter an industry, and the importance of having it, will greatly differ between industries. In industries were resources are specialized, in the sense of being specific to a particular setting (Teece, 1980), pre-entry capabilities will be more important. Similarly, in industries where core competences and complementary assets (Teece, 1986) are important to innovate and profit from innovation, having access to those capabilities and assets will be an important decision factor relating to entry. Many empirical studies have shown that pre-entry experience is relevant for entering new niches within an industry, including laser printers (de Figueiredo and Kyle, 2006), hard disk drives (King and Tucci, 2002), and lasers (Klepper and Sleeper, 2005), among others. Although the creation of new industries is uncommon, empirical evidence also supports the importance of related experience on entry in a new industry, including new diagnostic imaging markets (Mitchell, 1989), ATMs (Lane, 1988), TV receivers (Klepper and Simons, 2000), and US automobiles (Klepper, 2002). Due to the complexity of IC devices, it is natural to expect previous related technical knowledge to be of particular importance for entering IC production.

Hypothesis 1: The probability of existing firms entering IC manufacturing increases with the relevance of their prior experience.

Hypothesis 2: The likelihood that an IC producer will become a leading firm in terms of market share is an increasing function of the relevance of their prior experience.

As mentioned in the previous section, the semiconductor industry is also famous for its spinoffs (Sporck, 2001). According to Moore and Davis (2004), the success of the early semiconductor industry, especially in the IC era, can be attributed to the individuals associated with these spinoffs. The large number of spinoffs created in SV by leaders of pioneering local firms appears to support Moore and Davis’s perspective (Bassett, 2002; Lécuyer, 2006; Klepper, 2009, 2010). These spinoffs often became leading producers themselves (Braun and Macdonald, 1982; Moore and Davis, 2004; Lécuyer, 2006).
There are several theories explaining the creation of spinoffs, and most of them feature the transmission of technical knowledge from the parent to the spinoff through the founder. Spinoff founders may imitate their prior employer’s know-how, focusing on a subset of its activities (Franco and Filson, 2006). Alternatively, they can explore a variant of the parent’s set of product that is not particularly profitable for the parent, but is sufficiently profitable for a spinoff (Klepper and Sleeper, 2005). A spinoff may even arise due to a disagreement between employer and employee regarding the value of an opportunity (Klepper and Thompson, 2010). All these theories feature an inheritance process by which the founder redeploys know-how generated during his tenure at the parent firm. Spinoffs differ from diversifying firms in that they are new entities, and that they are formed with directly applicable knowledge. Thus, we expect that there exists an overlap between the products initially pursued by the spinoffs and the products of their parents.

Hypothesis 3: Spinoffs are more likely to produce semiconductor products that were also produced by their parents.

The overlap between parents and spinoffs can go further than the products pursued. In general, we look at the products pursued by entrants because they are a proxy of the underlying processes, technologies, and knowledge that the founder takes with him/her to the spinoff. These are the truly important pieces of knowledge transmitted, but ordinarily they are very hard to observe, as they mostly consist on tacit and non-codifiable know-how. However, the characteristics of the semiconductor industry, and in particular of the technologies used to produce ICs, are well suited for this purpose. From the outset of IC production, three main types of ICs were produced: film, hybrid, and monolithic. Film ICs are produced by depositing film onto glass or ceramic substrates, which allows the creation and connection of discrete, but not active, components (diodes, transistors, etc.) (Kambata, 1963). Monolithic ICs are formed entirely within the semiconductor substrate by a process called diffusion, while Hybrid ICs are a mixture of film and monolithic IC technology, where only active elements are diffused into the semiconductor substrate and film is deposited to create passive elements and interconnects among the various elements.

Initially it was unclear which types of ICs were likely to capture the largest market. In fact, in the early years of the industry, many ICs were available in only film or hybrid versions. Yet monolithic ICs eventually became the technology of choice for the vast majority of IC types. If an inheritance process characterizes spinoffs, we should be able to observe it through the technology the spinoff chooses to produce ICs. In particular we can state that:

Hypothesis 3C (Corollary): Spinoffs of firms producing Monolithic ICs are more likely to produce Monolithic ICs at entry than other entrants into IC manufacturing.

Hypotheses H1–H3 conform in large part to what has been shown in prior literature. The difference of these hypotheses with existing works is the level of detail we are able to introduce, thanks to the precise nature of our data. Being able to assess the importance of the relatedness of prior experience will be key for comparing hypotheses borne out from heritage with hypotheses based on agglomeration.

The idea of “agglomeration economies” dates back to the work of Alfred Marshall (1890) on external economies of scale. The concept is that co-located firms face lower costs when accessing co-located specialized assets, experience savings due to labor market pooling, and enjoy the benefits of knowledge spillovers. Not surprisingly, the knowledge spillover component is particularly important for technology-based firms such as semiconductors. Being located in a cluster facilitates the process of acquiring knowledge in different levels. First, agglomeration facilitates the process of identifying individuals that might be valuable sources of knowledge for a firm by maximizing mutual accessibility, thus facilitating knowledge exchange (von Hippel, 1987; Helsley and Strange, 1990; Duranton and Puga, 2004). Second, if relocation is costly and thus employees with critical knowledge are likely to stay local, the presence of a cluster will allow greater mobility and, as a result, facilitate dispersion of relevant knowledge in the cluster, helping the firms located there (Pakes and Nitzan, 1983; Cooper, 2001; Breschi and Lissoni, 2006).
An extensive literature on industry cluster has provided evidence that firms in clusters perform better in a number of dimensions, including innovation (Baptista and Swann, 1998; Kelly and Hageman, 1999), productivity (Henderson, 2003), and employment (Glaeser et al., 1992). At an aggregate level, strong industry clusters are also associated with faster growth in entrepreneurship, improved levels of startup employment, and with promoting the emergence of related industry clusters (Delgado et al., 2012). The specific economies that make a cluster attractive will vary across industries (Alcácer and Chung, 2014).

SV is probably the better-known example of an industry cluster, certainly a place where the benefits of agglomeration must be at play. In semiconductors, two salient factors that are particularly relevant for the possibility of capturing of knowledge spillovers have been well documented. First, the semiconductor industry is notorious for accounts of informal sharing of information between engineers of different companies (Bassett, 2002). This informal exchange of information can be beneficial, even if it happens between competitors (von Hippel, 1987; Saxenian, 1994). Second, if knowledge is sufficiently tacit and embodied in human capital, technological spillovers may require the movement of an employee from one firm to another rather than just informal contacts between employees. The high mobility of workers in this industry is well known. Almeida and Kogut (1999) as well as Fallick et al. (2006) show that inventors and knowledge workers in semiconductors and computers respectively were indeed more mobile in clusters. For example, Bassett (2002) describes how Frank Wanlass, an engineer at the forefront of Metal Oxide Semiconductor (MOS) technology in Fairchild, was critical for the establishment of MOS capabilities in both General Microelectronics and General Instruments, two firms where he subsequently worked.

The presence of geographically concentrated knowledge spillovers should thus benefit co-located firms, as it helps them stay current with the latest developments of the industry. Moreover, while existing theory does not directly link knowledge spillovers with firm entry, several studies have linked agglomeration economies with new firm formation and performance. Empirical evidence shows that strong clusters with a well-built presence of supporting and related industries facilitate the growth of entrepreneurial activity, the formation of new establishments of existing firms, and improve the level of employment at young startups (Delgado et al., 2012). There are also a number of studies that relate regional characteristics and rates of entrepreneurship, defining which factors can influence the formation of “clusters of entrepreneurs.” The concentration of strong incumbents in the city is among these factors (Chatterji et al., 2013).

Based on the existing evidence of widespread knowledge spillovers through informal exchanges of information or employee mobility in SV, we expect entrants that located there to be better able to adopt the latest developments in the industry and perform better in the long term. While this was not evident at the time, it is now clear that producing Monolithic ICs was critical for success and survival in IC production. SV was distinctive from the onset in the number of firms producing Monolithic ICs. If agglomeration economies help entrants to adopt the leading technology, we should expect firms entering in clusters, and particularly in SV, to be more likely to adopt monolithic production. These are explored in the following hypotheses:

Hypothesis 4: Entrants in clusters, particularly in SV, are more likely to adopt the frontier technology (monolithic) at entry.

Hypothesis 5: Firms in clusters that did not adopt the frontier technology (monolithic) at entry are more likely to move to the frontier.

It is interesting to compare these hypotheses derived from the tenets of agglomeration with $H_1$–$H_3$ that derive from consideration based on heritage. While $H_1$–$H_3$ state that specific firms with a given background will have advantages in entering IC production and adopting a given technology at entry (monolithic ICs), $H_4$ and $H_5$ suggest that any firm located in a cluster will have an advantage in adopting at entry, or later migrating to, the leading technology. The hypotheses are not competing, as they can both be true simultaneously. However, the telling signs of each theory are distinct and we thus can differentiate if only some are at play. Differential firm characteristics related to heritage (founding conditions, production, performance, etc.) would be limited to existing firms and potentially founders of new firms with specific backgrounds. To the contrary, all firms located in a specific region will enjoy the benefits borne out from clustering.

A potential feature that can help further separate the effects of heritage and agglomeration is to look at the long-term performance of new entrants. Helfat and Lieberman (2002) propose that pre-entry resources and capabilities also affect how new firms will learn and adapt as they develop in time. The imprint of pre-entry skills is long lasting. We have seen that agglomeration economies may facilitate entry by lowering entry costs due to savings on workforce...
search and accessibility to cutting-edge knowledge. If these benefits are long lasting, we should expect that entrants in clusters are more likely to become industry leaders:

*Hypothesis 6: Firms in clusters are more likely to become industry leaders.*

4. Data

The task set forth in the hypotheses is challenging to test, as it requires comprehensive and detailed data on firms in the industry for a number of years, including its time of founding, location, founders, its initial capitalization, the products they pursued, and even the technology used to produce them. This type of data is very difficult to collect and organize, but its richness allows studying the development of the entire industry in a period that is particularly interesting: its formative years. Moreover, while our hypotheses pertain to the period when ICs were being developed and introduced into the market, to evaluate the importance of organizational heritage, we need to collect information on what potential diversifiers were doing before the advent of ICs. We thus collected information on producers in the semiconductor industry since the beginning of the industry. This section describes the identification of data sources and the methodology used to collect and structure the data used to test the hypotheses.

4.1 Firm identification, location, and production

For any exercise in examining the development of an industry through firm entry and performance, two groups of firms must be identified: potential diversifier entrants into the industry, and the firms that decide to enter. Industry-wide publications are particularly rich sources to gather data necessary to identify such firms, and buyers’ guides and other indexes have previously been used for industry studies (Buenstorf and Klepper, 2009). Additionally, the need for detailed information such as what products are produced and the location of each firm lends itself rather naturally to a buyers’ guide and other industry periodicals that identify producers.

The Electronics’ Buyer’s Guide (EBG) met the data requirements and was identified as a source of firm data. The EBG listed a large number of electronics and electronics-related products each year, and indicated which firms were producing each product. We collected data on four semiconductor-related products that are particularly important for examining the industry—transistors, active modules, diodes, and ICs. The data collected contains complete producer data, including location for each firm, for approximately 3000 producers on an annual basis between 1949 and 1987. This enables us to determine how long each producer survived within the industry.

Given that four regions of interest had been identified using information on the previous location of electronics clusters (Boston, Los Angeles and New York City) and the prominence of SV, the Census Bureau’s definitions of Consolidated Metropolitan Areas were consulted to determine which firms were located within these regions. Additionally, firms producing products related to ICs were identified in the year preceding the introduction of this product category in an effort to determine potential entrants. The original location of these firms was also recorded for use in analyzing the number and direction of firms that located IC production in a region different than their previous production.

All of the data collected were digitized and organized into a MySQL database for analysis purposes.

4.2 Firm background/heritage data

To determine the backgrounds of firms within the semiconductor industry, a large effort involving searching through a variety of sources was pursued. This effort included the collection of novel background data from a number of sources as well as the use of some preexisting background/heritage sources. Ultimately, the effort resulted in a large amount of novel heritage information, especially for firms outside SV.

In pursuing heritage data for all firms, a few natural categories of firms were used to provide structure to the data collection effort. Firms that were preexisting prior to their entry into ICs are considered diversifying firms, while firms that were founded to pursue semiconductor production were classified as new firms. Although the classification of firm heritage for all firms in the data set was the desired result, a number of firms were not classified through these efforts, and these firms were denoted as unclassified. The classifications used are mutually exclusive and collectively exhaustive, meaning, for example, that any evidence classifying a firm as a diversifier would preclude it from being a startup. To help classify the technical proximity of diversifying firms with ICs, the EBG was consulted to determine
if the firm had previously produced products related to ICs. Technical information and engineering knowledge were used to determine which products were related to ICs, and the first year of a firm’s production of each of these products was retrieved from the EBG. Additionally, the EBG included an index each year, listing all firms that were producing electronics or electronics-related products. This index was searched for all firms in the data set in an attempt to identify the first year that each firm produced an electronics or electronics-related product. Finally, the last variety of diversifying firm was a firm that diversified from other nonelectronic products and had produced such a product for at least 5 years prior to entry in transistors or ICs. Evidence of this type of firm activity was gathered using several types of sources but was focused on identification of the date of founding or first production. Sources included general web searches, incorporation records, Dunn & Bradstreet’s Million Dollar Database, Who’s Who and Lexis-Nexis.

For firms that were not classified as diversifying firms, existing listings of firm histories were consulted. For IC firms, a total of 101 firms were featured on the Integrated Circuit Engineering (ICE) listings that were previously used to gather performance data, and for 92 of these firms, Klepper (2009) traced the pre-entry history of each firm, including whether it was a spinoff and if so, its “parent” firm (i.e., the prior semiconductor employer of the spinoff’s founder). Additionally, a genealogy of SV semiconductor producers compiled by the trade organization Semiconductor Equipment and Materials International (1995) was used to trace the origins of the other nondiversifiers located in SV. These efforts exhausted all preexisting collections of information about new semiconductor firms and spinoffs, requiring a bit of creativity regarding further data collection.

Finally, the publication Electronic News served as an excellent source for information on the founding of firms and mobility of key employees. Every edition of Electronic News between 1957 and 1987 was examined to identify the background of any remaining firms that had not been classified as diversifiers. Additionally, data from Who’s Who, Dunn & Bradstreet’s Million Dollar Database, the publication Leaders in Electronics, and general web searches were used to determine the founder(s) of as many nondiversifiers as possible, as well as the previous employer of each founder to determine whether the firm was a spinoff or a startup. Finally, state incorporation records were consulted. If a firm had no other supporting documentation for its heritage classification and was incorporated within 5 years of its first production of ICs, the firm was classified as a startup/spinoff, essentially a firm that we knew was a new firm, but its exact origin was not known. Of the 600 IC firms identified, 525 were classified while 75 were not able to be classified.

The combination of both novel data and existing data, as noted above, allowed us to create a more comprehensive picture of the industry for analysis of the industry over time.

5. Results

This article examines the growth of SV, considering the role that both the increasing concentration of the industry, as well as the entrants’ heritage had in the process. In our data, entrants are classified as de novo or diversifiers. De novo corresponds to firms that do not have prior production experience, while diversifiers are firms that existed prior to entering IC production. A de novo firm is classified as a spinoff if the founder has prior experience in the industry and as a startup if we did not find information on prior relevant experience. The evidence of new firm formation among IC entrants seems telling. New firms accounted for a third of all IC entrants, with 16% of entrants being categorized as a de novo firm and 18% as spinoffs. The proportion of entrants with confirmed previous experience

7 Products related to integrated circuits, listed in order of technological proximity: transistors, diodes, active modules.
8 Any firm that produced a product at least 5 years prior to its entry in transistors or integrated circuits was listed as a producer of that product, and the product produced by the firm that was most closely related to transistors or integrated circuits was used as the classification for the firm’s technological background.
9 If this year was at least 5 years prior to the firm’s first transistor or integrated circuit production, the firm was classified as an electronics diversifier. If a firm was a semiconductor diversifier, this classification took precedence over the electronics diversifier classification. Essentially, the experience that was most closely related to transistors or integrated circuits was used as the firm’s only heritage.
10 Electronic News was a weekly tabloid-like publication that featured a large amount of information on rumors and developments within the industry.
11 Electronic News was first published in 1957.
in semiconductors is just over 18%, while 21% are diversifiers with experience in electronics. Finally, 27% of entrants are either diversifiers with no experience on semiconductors or electronics, or firms whose prior experience could no be determined.\(^{12}\)

These figures are a good starting point to explain how the most relevant cluster in the industry emerged in regions that was previously isolated from the industry. Almost half of entrants into ICs were either new firms or diversifiers with no experience in semiconductors or electronics. Thus, it is not totally surprising that the existing concentration of the electronics and early semiconductor industries in the east coast might have had only a limited influence in the subsequent location of the IC industry. Looking at the firms that were ultimately successful reinforces this notion. Of the 37 firms in the data set that achieve top 20 status in ICs production at any time (through 2002), 24 of them are spinoffs. To better understand how these firms could enter and ultimately be successful, we analyze the type of products and technologies adopted by diversifiers and spinoffs.

**Hypothesis 1 (H1)** aims at evaluating the importance of previous relevant experience of diversifying firms in determining entry into new industries or segments. For this purpose, we evaluate the rate at which preexisting firms in the semiconductor industry\(^{13}\) entered IC production using Cox Proportional Hazard Regressions. The key challenge for evaluating H1 is to classify potential entrants’ prior experience, which we do by means of their past products as reported in trade journals. To determine the relevance of a firm’s previous experience for entering ICs, we used the category of its products listed in the EBG. If the firm had more than one product category listed, we used the one that was more closely related to ICs. In the product categories present in the EBG in 1964, there were three categories that we identified as having very similar functionality to ICs: active modules, diodes, and transistors. Based on expert knowledge, we considered that transistors were the closest to ICs, followed by active modules.

The sample for this analysis included all firms producing active modules, diodes, or transistors in 1964, the year prior to the first listing of ICs in the EBG. Potential entrants included 67 diode firms, 51 transistor firms, and 213 active module firms, for a total sample of 331 potential entrants. Of the 331 potential entrants, 37 started producing ICs in 1965, and an additional 53 firms enter IC production through 1987. Each product category is represented by a dummy variable in the models. The regression also included regional controls, to capture if potential diversifiers in the key clusters were more likely to enter IC production.

Coefficient estimates are reported in Table 1, where the omitted category is Active Modules. By large, the most important coefficient for entering IC production is having experience producing transistors. This provides interesting insights about H1 as it implies that not any experience matters. Only the closest related experience had a positive effect on affecting entry into ICs. The results also show that firms in traditional clusters were as likely to enter as those outside any of these regions. The only regional coefficient that was marginally significant was that of SV, suggesting that diversifiers located there were more likely to enter ICs. However, it is important to note that, at the time ICs were invented, SV was not yet an important cluster. In fact only 15 of the 331 potential entrants were located there. Considering the growing importance of clustering over the period studied, in Model 1.3, we introduce an extra variable that counts the yearly number of active IC producers in the cluster where the firm is located, or if the firm is not in any cluster, in the city it is located. While the coefficient estimate is positive, it is not significant. These observations provide initial insights to start piecing together the history of the industry in SV. As ICs became the centerpiece of the semiconductor industry, only prior experience in transistors seems to have allowed a transition of existing firms into this new and growing area. This knowledge was concentrated in a handful of firms and two of the leading innovators were outside the traditional clusters. In particular, Texas Instruments was based in Texas and Fairchild was in SV.

Before considering the performance of diversifier firms based on their background (H2), we will consider the remaining drivers of entry into the industry. As noted above, spinoffs account for 18% of all ICs entrants. Existing work suggests that these spinoffs will be carriers of knowledge from their parent firms, which is precisely the focus of **Hypothesis 3 (H3)** and its corollary (H3C). This is quite important for SV, as most of these spinoffs were founded in that region and came out from the leading producers at the frontier of knowledge. Testing H3 and H3C requires

---

12 Given the extensive efforts done to gather firms with relevant experience, it is hard to imagine that these firms have any expertise relevant to integrated circuits.

13 Note this analysis is done only considering preexisting semiconductor firms, and not other potential diversifiers. The reason for doing this is twofold: These are the firms with the closest relevant knowledge, and this is the set of potential entrants for which we have the most comprehensive data set.
analyzing the overlap of activities between parents and spinoffs. This is not straightforward and requires structuring the data in a way that allows us to consider this issue. The EBG listed the main categories of IC products over time, which frequently changed. By examining EBG naming conventions, leveraging technical knowledge of the product categories, and analyzing the production of firms that were active in categories introduced and/or eliminated over time, the IC product categories were organized into 8 broad categories and 50 narrow categories.14

Using the collected information on spinoff and their founders, parent firms were identified for 108 of the entrants in the industry, with 8 in Boston, 9 in Los Angeles, 9 in New York, 54 in SV, and 28 located outside the main industry clusters. The analysis included all spinoff firms with parents that had production data in the EBG, which reduced the sample to 99 firms. As a first look at whether spinoff production was related to parent production, we performed a simple analysis examining the frequency with which overlap occurred along with lone spinoff and lone parent production. The results are shown below in Table 2.

The results show that while parent firms are often producing in areas that their spinoffs are not, the same cannot be said of spinoff firms. At the time of entry, only 4% of spinoffs produced products that their parents did not produce. This result is the same whether we use broad or narrow technical categories. This provides evidence that spinoff production is influenced by parent production. Yet, there may be several confounding factors here. The overlap could be related to the types of products that spinoffs are producing, their location, or the time at which they enter, which may be associated with particular industry trends. A more detailed, structured analysis will help us determine what is actually at play here.

To analyze how parent production influences spinoff production, we produced up to eight observations for each spinoff, corresponding to the broad IC types actively being produced by firms in the industry at the time the spinoff entered. For each product type and spinoff, a production dummy was generated, which equals 1 if the parent produced that given product within 1 year before or after the spinoff’s entry and 0 otherwise. Similarly, the corresponding dependent variable was set equal to 1 if the spinoff produced the product type within 1 year of its entry and 0 otherwise.

14 The broad product categories include film, hybrid, monolithic custom, monolithic logic, monolithic linear, monolithic memory, monolithic microprocessors, and monolithic other. The narrow product categories further delineate within these eight broad categories. The detailed listing of these 50 categories can be provided by the authors upon request.
We then estimated a probit model where the coefficient estimate on the parent production dummy is expected to be greater than 0, reflecting an increased likelihood that a spinoff firm produced a given product if its parent firm produced it. In the estimation, we also include dummies for the eight product types, year of entry, and an SV region dummy, to control for overlaps in spinoff and parent production due to any of the particular factors of products, industry trends, and regions, respectively. The SV dummy was included due to the large proportion of spinoff firms that are founded in SV. Given that the region has been heavily studied, there is a large amount of firm heritage data available for firms there, raising a concern that more short-lived, lower-performing spinoffs may have been identified in SV as compared to other regions. This dummy served to control for any difference in product knowledge inheritance due to this perceived difference in spinoff identification information. Standard errors were computed by clustering observations for each parent firm. The coefficient estimates of the probit regressions are reported below in Table 3, with year and product coefficient estimates suppressed.

Throughout each of the specifications, the parent production coefficient estimate is positive and significant at the 0.01 level, implying that spinoff firms were more likely to produce a given product if their parent also produced it, regardless of product type or entry year. The inclusion of product, year, and SV dummies do not change the significance and only marginally change the magnitude of the parent production coefficient estimate. The SV coefficient estimate is not statistically significant, suggesting that there is not a significant difference in the ability of spinoffs to learn from their parents inside and outside that region. The analysis was repeated at a more disaggregated product level, which resulted in similar findings.15

The analysis at the product level is informative for spinoffs, but does not have a correspondence for de novo or diversifying entrants. Another way of looking into whether firms learn from their heritage or from their region, is to look at the technology they used to produce ICs. As noted in Section 3, there were three different technologies to produce ICs: Monolithic, film, and hybrid. Initially it was not evident which would come to dominate the industry but, over time, monolithic became the technology of choice. The adoption of this technology by spinoff of monolithic producers, or by firms that start their operations in SV, a region largely populated by monolithic producers, can be interpreted as leveraging pre-entry knowledge based on heritage or clustering respectively. This is the intent of the corollary of Hypothesis 3 (H3C), as well as Hypothesis 4 (H4).

To test H3C and H4, we use a probit regression model. The dependent variable is a 1–0 variable equal to 1 if the firm produced a monolithic IC in its first year of semiconductor production and 0 otherwise. We include a dummy for each of the regional clusters to test whether the likelihood of producing monolithic ICs at entry is greater in any of the clusters, and in SV in particular, as predicted in H4. We also control for the technological background of the firm, since we can expect that experience in closely related technologies will make it more likely for the firm to be active in the monolithic technology when first entering IC production. These technical background dummy variables include transistors, diodes, active modules, and other electronics,16 in order of technical proximity to ICs.

15 To test the hypothesis at a narrower level of production, the eight product categories were further disaggregated into 50 types that were either technically different or served different markets. For example, various types of logic circuits such as Resistor-Transistor Logic and Transistor-Transistor Logic were separated in this analysis, whereas Microprocessors and Microcontrollers could not be separated as they were actually reported as a single category for several years. Up to 50 observations for each spinoff were created corresponding to the narrow IC types that were actively being produced by firms in the industry at the time the spinoff entered. After the disaggregation of product categories, a total of 1341 firm-product-year observations remain. Standard errors were again computed by clustering observations at the parent firm-product level.

16 Note that this analysis considers a background in electronics. This is different from what we did in Table 1 where we only considered potential entrants with experience in semiconductors. The difference is that in this analysis we start...
We also consider the possibility of differential effects according to the background of firms that do not have experience in closely related technologies, including diversifiers and new firms. Within new firms, spinoffs are also singled out, as we expect these to be endowed with capabilities inherited from their parents. Finally, we control for the year of entry to allow firms starting later to be more likely to adopt the monolithic technology at entry, as its dominance became more evident over time. The sample includes 600 firms, including 78 in Boston, 93 in Los Angeles, 115 in New York City, and 90 in SV. The vast majority of these firms had no previous relevant experience, with 275 new firms (or firms with unknown histories) and 87 diversifiers from distant industries. There are 238 diversifiers from electronics or semiconductors, of which 44 were active in transistors, 43 in active modules, 23 produced diodes, and 128 electronics.

The coefficient estimates are reported in Table 4. In Model 4.1, we include only the regional variables. In 4.2, we add the technological and firm heritage controls, and, in 4.3, we include a “spinoff of monolithic parent” dummy. Boston has a negative coefficient estimate, while Los Angeles, New York, and SV regions have positive coefficient estimates. However, only the coefficient estimate of SV is consistently significant, at the 0.01 level. The coefficient estimates for technological background are ordered as expected (the excluded category are new firms or firms with unknown background). Among firms with prior semiconductor experience, only the coefficient of transistor background is positive and significant. The coefficients of active modules and diodes are close to zero and not significant. The coefficients related to other diversifiers, including electronic producers and firms from unrelated industries, are not significant in Model 4.3. These results indicate that among all diversifiers, the only experience that mattered for increasing the likelihood of adopting monolithic production at entry was prior transistors production. The year of entry coefficient estimate is positive and significant at the 0.01 level, indicating that firms entering later were more likely to produce monolithic ICs as well. Spinoffs of monolithic producers are more likely to start as monolithic producers, which bears support for H3C.

These results suggest that firms located in SV were more likely to produce monolithic ICs at entry than firms located elsewhere, while firms located in other industry clusters were comparable with those firms located outside a cluster, which partly supports H4. According to H4, firms located in clusters should have a greater probability of adopting monolithic at entry. This is only the case for SV. The overwhelming concentration of monolithic producers in SV could explain why this coefficient is only significant for this cluster. This is a result that has to be interpreted cautiously, as over half of the entrants in SV were spinoffs, and given the support of H3C we should expect those entrants to be monolithic producers as well. However, if spinoff heritage alone explains monolithic entry in SV, the inclusion of the spinoff of monolithic parents dummy would eliminate the significance of the SV coefficient. This was not the case. There is greater share of non-spinoff firms starting as monolithic producers in this region in comparison to others, which explains the continued significance of the region’s dummy. In sum, the results do suggest that it was easier for new firms in SV to recognize and have access to this frontier knowledge, and to start their operations based on it.

from a known sample of IC entrants, while in Table 1 we had to identify coherent set of potential entrants, which is much harder to assemble.
Table 5 puts the estimates in perspective, indicating that 89% of firms in SV produced a monolithic IC at entry compared to the 35%–48% of firms in the other regions. The table also shows clearly how firms with a transistor background were more likely (73%) to enter the production of monolithic ICs at entry when compared to firms with other technical backgrounds (35%–64%). Not surprisingly, most of the spinoffs are also extremely likely to enter as monolithic producers (82%), which explains also the high rate of monolithic producers among new firms, many of which we have identified as spinoffs, especially in SV.
A more challenging test for the existence of knowledge spillovers is to analyze if firms that did not adopt monolithic at entry migrate to monolithic production at some point in time. This is the purpose of Hypothesis 5 (H5). To test H5, we estimate a Cox proportional hazards model where, similarly to the previous regression, we also include four regional dummies, background dummies, and a time of entry variable. These variables allow for heterogeneity across firm characteristics, regions, and time. We expect firms located in clusters to be more likely to migrate to monolithic technology earlier thanks to knowledge spillovers that occur in agglomerated regions. Firms with related technological background should also be more likely to shift to producing monolithic ICs earlier because the similarity in knowledge base should facilitate the transition. The sample includes 296 firms, with 55 located in Boston, 52 in Los Angeles, 73 in New York City, and 12 in San Francisco. Only firms that entered prior to 1987 were included in this sample because adoption after entry could not be observed for firms starting production in the last year of our data. As before, some of these firms had previous experience in semiconductors with 17 active in transistors, 32 in active modules, and 15 in diodes. Additionally, 139 firms had some experience, with 90 producing electronics, and 48 with experience in unrelated industries. There were 81 new firms, including 19 spinoffs.

Coefficient estimates are reported in Table 6. As can be observed, none of the coefficients for the industry clusters, including SV, are statistically significant, which does not support H5. The entry year coefficient estimate is less than 1 and significant at the 0.01 level, indicating that firms that enter ICs later were less likely to adopt monolithic IC technology after entry. The only coefficient related to technical background that is positive and significant is that of transistor production. This was the category more closely related to ICs.

Table 7 puts these results in perspective. Overall, Monolithic IC adoption after entry rates are low, around 12%. In addition, adoption rates do not vary much across either regions or firm background with two exceptions. Firms with pre-entry experience in transistors are more likely to shift to monolithic, and firms in SV have a higher post-entry adoption of monolithic. However, the difference between SV and New York is not impressive, which seems inconsistent with the idea that firms located in SV had much better access to spillovers which would help them move quicker to the technological frontier.
Summing up the evidence shown in this analysis, we have several pieces of evidence supporting both the role of heritage and clustering in the establishment of SV, albeit with weaker results on the cluster. First, heritage mattered for diversifiers as well as for new entrants. For potential entrants, we see that firms with closely related prior experience were more likely to enter ICs. Presence in a cluster did not seem to matter, with the exception of SV where we

### Table 7. Backgrounds of firms adopting monolithic IC after entry/total firms that did not adopt monolithic IC at entry, 1965–1987a

<table>
<thead>
<tr>
<th>Region</th>
<th>Active module</th>
<th>Diode</th>
<th>Electronics</th>
<th>Transistor</th>
<th>New</th>
<th>Unknown</th>
<th>Other diversifier</th>
<th>Total</th>
<th>Share</th>
<th>Spinoff</th>
<th>Share spinoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOS</td>
<td>1/6</td>
<td>1/5</td>
<td>0/7</td>
<td>0/2</td>
<td>2/21</td>
<td>0/2</td>
<td>0/8</td>
<td>4/51</td>
<td>0.08</td>
<td>1/4</td>
<td>0.25</td>
</tr>
<tr>
<td>LAX</td>
<td>0/3</td>
<td>0/1</td>
<td>1/13</td>
<td>0/1</td>
<td>1/12</td>
<td>2/8</td>
<td>0/10</td>
<td>4/48</td>
<td>0.08</td>
<td>1/3</td>
<td>0.33</td>
</tr>
<tr>
<td>NYC</td>
<td>1/5</td>
<td>0/1</td>
<td>3/18</td>
<td>3/6</td>
<td>2/8</td>
<td>1/14</td>
<td>1/10</td>
<td>11/62</td>
<td>0.18</td>
<td>0/1</td>
<td>0.00</td>
</tr>
<tr>
<td>SFO</td>
<td>0/0</td>
<td>1/2</td>
<td>1/3</td>
<td>0/0</td>
<td>0/3</td>
<td>0/0</td>
<td>0/2</td>
<td>2/10</td>
<td>0.20</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>Other</td>
<td>2/14</td>
<td>1/3</td>
<td>4/40</td>
<td>2/3</td>
<td>3/29</td>
<td>1/20</td>
<td>2/16</td>
<td>15/125</td>
<td>0.12</td>
<td>1/11</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>4/28</td>
<td>3/12</td>
<td>9/81</td>
<td>5/12</td>
<td>8/73</td>
<td>4/44</td>
<td>3/46</td>
<td>36/296</td>
<td>0.12</td>
<td>3/19</td>
<td>0.16</td>
</tr>
<tr>
<td>Share</td>
<td>0.14</td>
<td>0.25</td>
<td>0.11</td>
<td>0.42</td>
<td>0.11</td>
<td>0.09</td>
<td>0.07</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aFirms entering in 1987 excluded because adoption is not observable for those entering that year; adoption for firms entering in 1965 cannot be observed because it is the first year recorded.

### Table 8. IC market share analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>M8.1</th>
<th>M8.2</th>
<th>M8.3</th>
<th>M8.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>78</td>
<td>-0.10</td>
<td>-0.28</td>
<td>-0.17</td>
<td>-0.34</td>
</tr>
<tr>
<td>(0.67)</td>
<td></td>
<td>(0.66)</td>
<td>(0.71)</td>
<td>(0.70)</td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>93</td>
<td>-0.71</td>
<td>-0.82</td>
<td>-1.04</td>
<td>-0.78</td>
</tr>
<tr>
<td>(0.80)</td>
<td></td>
<td>(0.82)</td>
<td>(0.91)</td>
<td>(0.85)</td>
<td></td>
</tr>
<tr>
<td>New York City</td>
<td>115</td>
<td>-1.59</td>
<td>-1.77*</td>
<td>-1.89*</td>
<td>-1.76</td>
</tr>
<tr>
<td>(1.06)</td>
<td></td>
<td>(1.07)</td>
<td>(1.03)</td>
<td>(1.08)</td>
<td></td>
</tr>
<tr>
<td>Silicon Valley</td>
<td>90</td>
<td>2.25***</td>
<td>1.89***</td>
<td>0.59</td>
<td>0.76</td>
</tr>
<tr>
<td>(0.43)</td>
<td></td>
<td>(0.45)</td>
<td>(0.57)</td>
<td>(0.56)</td>
<td></td>
</tr>
<tr>
<td>Transistors</td>
<td>44</td>
<td>0.97**</td>
<td>1.83**</td>
<td>2.59***</td>
<td></td>
</tr>
<tr>
<td>(0.49)</td>
<td></td>
<td>(0.80)</td>
<td>(0.78)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active modules</td>
<td>43</td>
<td>-0.76</td>
<td>1.24</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>(1.04)</td>
<td></td>
<td>(1.23)</td>
<td>(1.21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diodes</td>
<td>23</td>
<td>-0.51</td>
<td>1.46</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>(1.23)</td>
<td></td>
<td>(1.35)</td>
<td>(1.28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td>128</td>
<td>-2.00*</td>
<td>-0.19</td>
<td>-0.42</td>
<td></td>
</tr>
<tr>
<td>(1.03)</td>
<td></td>
<td>(1.22)</td>
<td>(1.20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other diversifiers</td>
<td>87</td>
<td>-1.55</td>
<td>-0.03</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>(1.07)</td>
<td></td>
<td>(1.29)</td>
<td>(1.24)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinoff</td>
<td>51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.82)</td>
<td></td>
<td>(0.82)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolithic production at entry</td>
<td>300</td>
<td>NE</td>
<td>NE</td>
<td>1.14**</td>
<td></td>
</tr>
<tr>
<td>Fairchild (3 deg)</td>
<td></td>
<td></td>
<td></td>
<td>(0.51)</td>
<td></td>
</tr>
<tr>
<td>Entry year</td>
<td>600</td>
<td>-0.06**</td>
<td>-0.06**</td>
<td>-0.08**</td>
<td>-0.05*</td>
</tr>
<tr>
<td>(0.03)</td>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>121.48**</td>
<td>112.93**</td>
<td>155.58***</td>
<td>103.66*</td>
<td></td>
</tr>
<tr>
<td>(58.27)</td>
<td></td>
<td>(56.34)</td>
<td>(58.47)</td>
<td>(59.11)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td></td>
<td>-113.2</td>
<td>-105.7</td>
<td>-84.18</td>
<td>-94.34</td>
</tr>
</tbody>
</table>

Standard errors in parentheses. ***P < 0.01, **P < 0.05, *P < 0.1.
do find potential entrants to be more likely to enter ICs. Yet, when looking at all entrants, we found that diversifiers were a small proportion of the total entrants in SV, with new firms, and spinoffs in particular, playing an important role. According to our results, the knowledge spinoffs brought from their parent establishes the ground for their activity. When considering SV, this becomes particularly important, as both spinoffs and other entrants that locate in SV were more likely to adopt monolithic ICs at entry. Even after controlling for the disparate share of spinoffs entrants in SV, the effect of this region over the likelihood of entrants adopting monolithic ICs at entry persists. Looking only at the time of entry suggests that spinoffs and other entrants in SV were both able to absorb the knowledge of the region and adopt the leading technology. The SV cluster does seem to play a role in establishing the right entry conditions, for spinoffs, startups, and diversifiers.

The final aspect of our analysis, which is precisely the objective of H2 and H6, is to inquire about the likelihood of becoming a leading firm. To test H2 and H6, we take advantage of the market share data published by ICE. This annual publication reported the top-10 and top-20 IC firms of the year in terms of sales. We use this as a measure for success, and specify a series of logit models where the dependent variable is a dummy equal to 1 if the firm ever attains top-20 market share status through 2002. The sample is composed by all firms that enter into IC production in our sample, which accounts to 600 firms. As in previous regressions, the independent variables include information on the location of the firm, its pre-entry experience, and its spinoff status. The regressions also include an entry year control, to capture how the likelihood of becoming a top producer changed with the timing of entry.

Coefficient estimates are reported in Table 8. As can be seen in Model 8.1, when considering only regional variables, it is evident that firms located in SV accounted disproportionately for leading firms. SV is the only coefficient that is positive and significant. Adding background variables in Model 8.2 shows that firms with an electronic background are less likely to become leading firms while firms with a transistor background are more likely to become top 20 firms. Finally, in Model 8.3 we add two dummies. One identifies entrants that were spinoffs, and the other identifies firms that produced monolithic IC since entry. The coefficient estimates corresponding to producing monolithic at entry could not be estimated, as all top 20 firms produced monolithic since entry. Consequently, the variable is dropped from the model, and the 300 firms that did not produce monolithic from entry are excluded from the estimation. The coefficient corresponding to spinoff entrants is positive and significant. Moreover, after introducing this variable, the coefficient of SV diminishes and is no longer significant, while the coefficient corresponding to having a transistor background almost doubles and remains significant. This reinforces the importance of heritage relative to location, as it indicates that while firms in SV were more likely to become leading firms, this is mostly explained by spinoffs entering in this region. Note that this does not rule out the possibility that agglomeration may facilitate the entry of spinoffs. In fact, our previous results indicate that it was easier to enter and to adopt the leading technology at entry in SV. However, in the long term the importance of pre-entry experience appears to be extremely relevant in determining industry leaders.

A further test that serves to emphasize how critical heritage and pre-entry experience in determining a firm’s future path can be is to look at the influence that just one key firm can have over an industry. The role of Fairchild Semiconductors and its many spinoffs in the evolution of the semiconductor industry is well known. In Model 8.4, we experimented with incorporating a dummy variable equal to 1 for all firms that are spinoffs with less than 3 degrees of separation from Fairchild.17 Remarkably, the coefficient is positive and significant at the 5% level, which indicates that firms related to Fairchild were more likely to become industry leaders.

The results presented above provide interesting insights about H2 and H6. Hypothesis 2 stated that the likelihood of becoming a leading producer was directly related with the relatedness of pre-entry experience. The results in Model 8.3 support this hypothesis, but in a stronger way than we anticipated. The only experience that seems to matter is that of diversifiers from very related technologies (in this case transistors), or from spinoff founders that were most likely working in the same field. Hypothesis 6 states that firms located in cluster were more likely to become leaders. While firms in SV were more likely to become leaders, this does not seem to be determined by location. After controlling for heritage in Model 8.3, the coefficient corresponding to SV greatly diminishes and is no longer significant. Examining the background of leading firms puts these results in perspective. Of the 37 firms in our database that ever achieve top-20 status, 24 were spinoffs. This result is more impressive if we take into account the effect of Fairchild. In our database, there are 39 spinoffs that are less than 3 degrees of separation from Fairchild. Of these, 16 eventually became industry leaders (41%). There were another 22 spinoffs in SV, of which 4 (18%) became industry leaders. This means firms that are Fairchild’s spinoffs, spinoffs of its spinoffs, or spinoffs of the spinoffs of its spinoffs.
leaders. Non-spinoff entrants, even the monolithic producers located in SV, tended to be short lived and none achieved a meaningful level of success.

6. Conclusions

In this article we analyze the relevance of agglomeration and heritage on influencing entry and success in IC production. The study is based on a comprehensive data set of firms constructed by identifying all active firms in four semiconductor-related areas present in the “Electronics’ Buyer’s Guide,” as well as all potential IC entrants, considered as firm that were active producing active modules, diodes, or transistors at the time ICs were introduced.

Our analysis supports both the role of heritage and clustering in the establishment of SV, albeit with particular characteristics. While we found that heritage and presence in SV did matter in terms of diversifiers that entered IC productions, these were but a small proportion of the total entrants in SV. New firms, and spinoffs in particular, played an important role in the evolution of the industry. This observation is quite important as it helps us understand why the semiconductor industry could grow detached from its geographic origins in the east coast. Our results show that new entrants, in particular spinoffs, became the driving force for the development of ICs and therefore for the overall industry. The heritage mechanism was seen as particularly important for spinoffs, which bring knowledge from their parent firms as the ground for their activity. Agglomeration economies were found to positively influence the likelihood of entry in SV and the propensity of these entrants to adopt the leading technology upon entry. However, agglomeration did not seem to help de novo entrants and diversifiers in SV to be successful in the long term. Leading firms were disproportionately spinoffs of other leading firms.

Our results are particularly salient when reflecting on SV. First, it was clear that the industry was based on new entrants, especially spinoffs. Shockley and Fairchild initially established the industry in SV, and a variety of new entrants, especially spinoffs, quickly gained preeminence locally and nationally. Moreover, our analysis shows that both spinoffs and other entrants that located in SV were more likely to adopt monolithic ICs at entry, the frontier technology that came to dominate the industry. Entrants in SV were thus able to absorb the knowledge of the region and adopt the winning technology. This could have occurred through a variety of mechanisms, including knowledge spillovers facilitated by proximity (von Hippel, 1987; Helsley and Strange, 1990; Combes and Duranton, 2006) and knowledge transmitted by local enhanced job hopping (Pakes and Nitzan, 1983; Cooper, 2001; Fallick et al., 2006). These mechanisms seem to play a role in establishing the right entry conditions, for spinoffs, startups, and diversifiers. However, when we analyze the likelihood of success, the conclusion is quite different. While firms in SV were more likely to become leaders, this does not seem to be determined by location but rather by the heritage of spinoffs of leading firms. This result questions if all firms located in cluster can benefit equally from agglomeration economies. Our results show that spinoffs performed better than diversifiers and other entrants within clusters. This contrasts with the usual account of clustering, where the benefits of agglomeration are available to all firms in the industry. This finding adds further support to the special role that spinoffs appear to play within clusters. For example, Cheyre et al. (2015) find that inventors moving to spinoffs disproportionately account for the excess mobility in clusters, allowing them to capture most of the knowledge spillovers resulting from such heightened mobility.

In technologically complex industries, knowledge spillovers across co-located firms are thought to be an important force. They enable firms in clusters to be more likely to be at the technological frontier and thus to perform better. As we saw, there were more semiconductor firms at the technological frontier in SV than elsewhere. But the diffusion of knowledge about monolithic IC production seemingly required it to be inherited/pass down within a firm rather than being transmitted across co-located firms. When examining whether firms that had chosen the wrong technology at entry were able to adopt the leading technology (monolithic ICs) post-entry, we found no difference between firms located in or out of SV. The only factor that seemed relevant was having prior experience in producing transistors, a technology that can be considered one of the antecedents of monolithic ICs. This observation is consistent with prior work highlighting the importance of decisions and capabilities at the time of entry. Helfat and Lieberman (2002) propose that the pre-entry experience of a firm has a great influence on the path chosen at the time of entry and on its future prospects of success. There is also empirical evidence supporting this notion. For example, Klepper and Simons (2000) find the US TV industry was dominated by firms that previously produced radios. Our findings further highlight the importance of entry decisions and capabilities. Yet, our research goes further. Firms that chose the wrong technology at entry have a hard time migrating to the leading technology, even in a region that was full of firms producing at the leading technology and that is known for its openness. We thus conclude that
co-location is of lesser importance than the endowment of the firm at the time of entry in terms of success, which is a novel result.

The main objective of this article was to help in our understanding of how clusters emerge and develop. We have explored the importance of two mechanisms, agglomeration and heritage. In the case of SV, it is evident that the growth of the cluster was fueled by the creation of new firms. Our results provide novel and interesting insights on the relative importance of agglomeration and heritage in the process that led to the creation of the many startups that led SV to local and national preeminence. De novo entrants, diversifiers, and spinoffs were all more likely to enter at the technological frontier in SV, but only spinoffs were more likely to become leading firms. After entry, being located in the SV cluster might not have been particularly advantageous. In fact, our evidence suggests that there was not much of a difference between being located in any of the IC clusters or elsewhere in the country.

The rate of development of the IC industry in SV was not different because it was the main industry cluster. It was new firms constantly being created that led SV to become what it is today. It has been long recognized that new firms are the driving force of SV. Consequently, great efforts and resources have been devoted to policies to incentivize the formation of “Clusters of Entrepreneurship” throughout the world (Chatterji et al., 2013). Our results provide some important insights that differ from prevailing view on this topic. “Clusters of Entrepreneurship” are often associated with lower costs of entry, greater supply of entrepreneurs (Glaeser et al., 2010), or with agglomeration economies themselves (Delgado et al., 2010). Our results suggest that all these mechanisms were more than likely at play in the emergence of SV. Moreover, they did help de novo entrants and diversifiers to get established and adopt the leading technology. However, in the long run, spinoffs outperformed all other types of entrants. The heritage process that imprinted spinoffs with lasting superior capabilities seems to be have been key in spurring the diffusion of IC technology and propelling SV to what it is today. SV became so successful not necessarily because it was a “cluster of entrepreneurs,” but because it was a “cluster of spinoffs.”

Acknowledgements

This article is partly based on work done by Jon Kowalski for his doctoral dissertation. Steven Klepper participated and provided significant insights in the initial stages of this research project. The authors thank Rosemarie Ziedonis for sharing longitudinal data she compiled on the sales of semiconductor producers. All errors are our own.

Funding

This research was supported in part by grants from the National Science Foundation (grants SBE-0965451, SBE-0738182, and SES-0727000). J.K. was supported by the Richard King Mellon Foundation, the Claire, and John Bertucci Fellowship, a Dean’s Fellowship from the Carnegie Institute of Technology, the Engineering & Technology Innovation Management (ETIM) program at Carnegie Mellon, and a research travel grant from the William P. Clements Center for Southwest Studies and the DeGolyer Library at Southern Methodist University. F.V. was supported by the NOS Chair in Innovation and Entrepreneurship at Católica-Lisbon. The views expressed in this article do not necessarily reflect the views of these organizations.

References

Spinoffs and the ascension of Silicon Valley


