Patenting an Industry:

Tracking Semiconductor Inventors in Silicon Valley and Beyond

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Abstract

This paper uses newly collected patent and biographical data to identify and profile semiconductor inventors and track their backgrounds. This data are used to study the famous cluster of semiconductor firms in Silicon Valley and make comparisons to firms in other regions. Logistic regressions are used to estimate probabilities that firms hire inventors from a given background, dependent on characteristics of the firm. These logit models test whether Silicon Valley firms behave differently than other firms outside the region in terms of inventor hiring and assess claims made about Silicon Valley by other authors.

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Introduction

The semiconductor industry has a rich and fascinating history, from the earliest transistors at Bell Telephone Laboratories to Intel's state-of-the-art microprocessors today. Germanium transistors were first created at Bell Labs in 1947 and by 1954, Texas Instruments had produced a transistor made from silicon. 1955 saw the founding of Shockley Semiconductor in Mountain View, California. This was the birth of the semiconductor industry in what would become known as Silicon Valley. While Bell and other large, diversified firms dominated the industry at the outset, Silicon Valley quickly became important as more and more firms cropped up there.

A defining feature of Silicon Valley has been the rate of spinoff firms. Many new entrants in the industry were formed by scientists unhappy at their previous firm who left to start their own, bringing colleagues and ideas along. One of the most famous incidents involved eight of Shockley's employees (the "Traitorous Eight") leaving to form Fairchild Semiconductor, which would become one of the most important firms in the industry. Fairchild itself spawned numerous spinoffs, including current industry leader Intel, founded by Robert Noyce and Gordon Moore. Before long, the old centers of the semiconductor industry were left behind. However, there are two notable exceptions: Texas Instruments (TI) and Motorola. Located in relative isolation in Dallas and Motorola, these firms continued to be successful in semiconductors without ever being part of the Silicon Valley cluster.

Many authors have attempted to provide explanations for the rise of Silicon Valley. Silicon Valley is considered to be an "agglomeration economy," and some attribute the continued clustering to the benefits of such an agglomeration. In this paper, I do not claim to have an explanation for the explosion of the semiconductor industry in Silicon Valley. However, the launch of Google Patents and other web-based resources have made it possible to track inventors and profile firm hiring patterns. The new data provide a unique and quantitative assessment of the commonly held views about Silicon Valley and its place in the industry.

Literature

John Tilton (1971) emphasizes the importance of Bell Labs, stating that Bell held the bulk of patents in the early years, and that former Bell employees were found all over in the industry. He also writes that large firms benefitted in the semiconductors due to the large research and development costs needed to stay at the forefront of the technology.

Historian Christophe Lécuyer (2006) focuses in part on indigenous factors in the San Francisco area that influenced the early growth of semiconductors in the region. He points to a burgeoning microwave tube industry and radio culture and the presence of Stanford University as major contributors. In particular, he credits Stanford engineering dean Frederick Terman for encouraging electronics research in the region. He also points to the electronics firms Litton Industries and Varian Associates for laying an additional foundation. These early firms were led by such engineers as Charles Litton, William Eitel, and Jack McCullough. Once the industry got started, Lécuyer believes Fairchild Semiconductor not only redefined electronics and entrepreneurship in Silicon Valley, but revolutionized the entire industry. He views the spirit of entrepreneurship as a key part of the clustering of firms there.

Stuart Leslie and Robert Kargon (1996) support the view that Silicon Valley's educational institutions gave it a great advantage over other regions; in particular, they see Stanford as a driving force under the leadership of Terman. They argue that Terman, "the father of Silicon Valley" attempted to emulate Massachusetts Institute of Technology's (MIT) success in driving industry in Boston. They note that other regions, such as New Jersey (home to RCA and Bell Telephone Laboratories), lacked technological universities of Stanford or MIT's caliber. They also credit pre-semiconductor firms such as Varian and Hewlett-Packard, along with Terman, for establishing the entrepreneurial culture of Silicon Valley. Leslie and Kargon also discuss Texas Instruments. They argue that TI benefitted from its relative isolation from the rest of the industry in that they could capture talented Texas engineers who might be reluctant to leave the area. However, they also note that TI suffered from a lack of research universities.

Stephen Adams (2011) cites many of the same factors as the previous authors, as well as the University of California, Berkeley, as contributors to the growth of electronics in general. However, he does not make a direct connection between these and the semiconductor industry, stating that it began with William Shockley. He does make a case that Stanford was a major source of Shockley and other semiconductor firms' early success due to cooperation and supply of graduates.

Steven Klepper (2009) compares the clustering of semiconductor firms in Silicon Valley to that of automobile firms in Detroit. In particular, he focuses on the propensity for firms in these regions to spawn spinoffs. He notes that both Silicon Valley and Detroit witnessed similarly disproportionate amounts of spinoffs. Klepper questions the argument that "traditional agglomeration economies" were the source of firm success in these regions, that is to say, technological spillover and easy access to a large labor pool. Instead, he finds that the most successful firms were spinoffs of the formerly most successful firms. Rather than attributing growth of clusters to there being advantages to locating a new firm in a cluster, he credits the fact that spinoffs simply tend to remain in the same region as their parents.

There is comparatively little literature on semiconductor hiring patterns and mobility. David Angel (1989) studies the labor market for semiconductor production engineers and inter-firm mobility of engineers. His method involved distributing surveys among engineers, to which he had a relatively low response rate. In contrast to Leslie and Kargon, Angel rejects the idea that local universities are a critical source of labor, since it is relatively easy for firms to recruit outside their regions. He also states that at the time of writing, the training found at San Francisco area universities could be found in many other places. Instead, he argues that access to a large pool of experienced workers is much more valuable. He finds that Silicon Valley firms exhibit a much higher turnover rate of employees than large firms in other regions.

Cristobal Cheyre, Steven Klepper, and Francisco Veloso (2010) used patents to analyze mobility of semiconductor inventors. They combine a theory of spinoff firms with an analysis of the frequency of inventors moving to different firms. They found that while Silicon Valley inventors had greater mobility, it was not to the benefit of all firms in the sense of having a larger local pool of labor. Instead, they argue that this mainly benefits new entrants, who hire away workers from the incumbents. Hence, the incumbents are at a disadvantage in their model, struggling to hold onto their employees and ideas. Ultimately, they contend that spinoffs were the defining feature that caused the semiconductor industry to agglomerate in Silicon Valley.

This paper presents a new approach not previously found in the literature. Instead of focusing on mobility, I address the specific origins of semiconductor inventors before coming to a firm. Angel's study, using surveys, could only address his contemporary time period. Using a combination of biographical and patent data, this study goes back to the earliest days of the firms' history. This level of detail in data allows a unique, quantitative perspective on the claims made by the technological historians.

Predictions

The prevailing views of agglomeration economies suggest large clusters like Silicon Valley are sustained and grow because of innate advantages of locating a firm within a cluster. These advantages include an increased local pool of labor and technological and intellectual spillovers. Klepper provides an alternative argument – that clusters form due to spinoffs. Based on these claims about agglomeration economies and the claims made in the existing literature about the semiconductor industry, I propose the following hypotheses:

1) *Silicon Valley firms are more likely to hire from other local firms than are firms located in other regions.*

The technological historians, such as Leslie and Kargon, emphasize the importance of a groundwork laid by existing electronics firms who were located in and around Silicon Valley before the arrival of Shockley. This would suggest the early firms within the San Francisco area would hire locally more than firms elsewhere. Additionally, a commonly stated advantage of agglomeration economies is the presence of large available labor pool. This would suggest more hiring from within the San Francisco area among later firms, once the industry became established there.

2) *Silicon Valley firms are more likely to hire from other semiconductor firms than are firms located in other regions*.

Silicon Valley was not one of the original centers of the semiconductor industry; originally, the bulk of the industry was located in Boston, Los Angeles, and New York. Over time, however, more and more firms cropped up in Silicon Valley until the industry became heavily concentrated. Because of this, it should be expected that inventing talent drifts toward Silicon Valley. This, combined with the expectation that local semiconductor firms hire from one another, means that Silicon Valley firms will be expected to hire more inventors from other semiconductor firms as a whole.

3) *New spinoffs are less reliant on hiring from parent firms once the industry becomes more established.*

One consequence of an industrial agglomeration is that there will be more options from which new firms can hire employees as the cluster grows. Hence, we might expect new spinoff entrants to have less reliance on bringing in employees from their parent firm. This should especially be expected of spinoffs who locate within a large cluster. Spinoffs not located in a cluster (Silicon Valley) would not have such an expectation, such as TI's spinoff Mostek.

4) *The presence of top-class local universities and research contributed significantly to Silicon Valley's inventor hiring.*

This hypothesis is strongly supported by historians, but Angel's view is that it local university influence is of only secondary importance. In particular, much credit is given to Stanford and UC Berkeley, especially Frederick Terman. Texas is home to several important research institutions, including the University of Texas at Austin and Texas A&M University. Philadelphia and New Jersey, the home bases of Philco and RCA, have the University of Pennsylvania and Rutgers University, but neither of these have a technological reputation of Stanford's heights. The fourth region, Phoenix, really only had the advantage of Arizona State University.

5) *Successful early diversifiers hired from outside their own firm rather than internally.*

Of the four diversifying firms in this study, only two (Motorola and TI) became long-term successes in the semiconductor industry. The other two (Philco and RCA) faltered, and never became significant players. Philco and RCA were already large electronics and appliance producers who diversified into semiconductors. Motorola was also established in electronics, but chose a unique strategy by locating their operations in Phoenix, rather than locally in Chicago. TI, compared to the other three firms, was smaller, and was a geophysical instrumentation producer. One possible reason the large East Coast firms did not succeed was from an overreliance on in-house inventors, whereas TI and Motorola sought fresh starts for their semiconductor divisions.

These hypotheses will form a framework for assessing the arguments of the past authors, as well as commonly held notions about industry clusters.

Data

The data used in the analysis are newly collected using a combination of web and print sources. The goal was to create a database of inventors who could then be categorized by origin and other information. The cornerstone of the process is Google Patents. Google Patents is a database containing all United States patents. More recent patents are recorded electronically by the United States Patent and

Trademark Office (USPTO), and can be accurately keyword searched. Older patents, like most used here, have been scanned and can be keyword searched through optical character recognition (OCR).

Data collection for this project is a four-step process. First, inventors are identified by searching patents assigned to each firm. Second, each inventor's previous patenting history is searched. Third, biographical sources are searched for each inventor. Fourth, information is gathered on inventors on the World Wide Web through normal Google searches.

Identifying Semiconductor Inventors

The process starts by identifying firms to be analyzed. The firms chosen were all players in the early semiconductor industry. Seven early Silicon Valley firms were chosen: Shockley Semiconductor, Fairchild Semiconductor, Rheem Semiconductor, Signetics, Amelco, National Semiconductor, and Intel. For comparison, five other firms were chosen: Motorola, Texas Instruments (TI), Mostek, Radio Corporation of America (RCA), and Philco. When an invention is developed for a given firm, the firm's name appears alongside the inventor as the "assignee." This makes it possible to search for patents assigned to any particular firm in Google Patents.

The process for building databases for each firm was roughly equivalent. First, a time frame is established, and set as a search parameter. Google Patents allows either application or issue date. For this analysis, the time frame always included the earliest dates the particular firm worked on semiconductors, and extended for several years after in order to get sufficient observations. To narrow to a specific firm, the firm's name is the keyword. The difficulty here is that many of the aforementioned firms were large electronics producers with vast numbers of non-semiconductor patents. Shockley, Rheem, Signetics, Amelco, National, Intel, and Mostek were semiconductor producers only, so the search terms were simply the firm name. Other firms were diversified, but had their semiconductor operations located in a single place. For these, the abbreviation for the state was added, as inventors' home city is printed on the patent. Fairchild Semiconductor was owned by Fairchild Camera and Instrument, so "Calif" was added to the search to eliminate the non-semiconductor patents. Similarly, to isolate Motorola's patents to only the Phoenix-based semiconductor division, "Ariz" was added. This method also applies to firms which were bought out by larger firms from another region. Shockley was bought by Clevite Corporation, Amelco by Teledyne, and Rheem was bought by

Raytheon. To locate semiconductor patents for these firms, post-buyout, "Calif" was added to the larger firms' names.

Table 1: Patent Search Summary

Firm	Total Patents	Application Range	Issue Range
Shockley	22	1956-1967	1959-1968
Fairchild	161	1959-1975	1960-1976
Rheem	44	1958-1973	1960-1974
Signetics	99	1962-1974	1966-1976
Amelco	14	1962-1971	1966-1973
National*	53	1963-1975	1966-1978
Intel	79	1970-1977	1972-1980
RCA	39	1949-1960	1950-1966
Philco	96	1954-1965	1957-1970
TI	141	1953-1961	1956-1972
Motorola	159	1954-1966	1972-1980
Mostek	67	1971-1980	1973-1984
Total	974		

Note: *This includes a several patents prior to National's reorganization and move to Silicon Valley under Charles Sporck. National's first Silicon Valley patent was applied for in 1968.

The most difficult firms to address were the large, diversified firms that did not have separate locations for their semiconductor divisions. These were Texas Instruments, Philco, and RCA. The method used for TI was to search all patents, year-by-year, and sort them by inspection. Patents which were semiconductor-related were recorded, and others were ignored. The inspection included keyword searching the patents for "semiconductor" and "transistor," as well as checking the diagrams and titles of the patents. The same process was used for Philco, but patents were searched for the whole period instead of year-by-year. To expedite this process for RCA, a slightly different method was used. Since RCA was a well-established electronics firm, semiconductors represented only a small fraction of its total patenting output. Each patent is part of at least one primary class, several of which have been noted to contain most of the semiconductor patents. The classes I used here are the same as used by Cheyre, Klepper, and Veloso (257, 326, 327, 365, 438). I wrote a set of Perl programs that take massed Google Patents searches, extract the patent numbers, and then search the USPTO database, separating out the patents which fall into these classes. With this trimmed-down list, the previously mentioned inspection method was then applied.

At the end of this process, a list of inventors who were employed by each firm can be extracted from the lists of patents. It is assumed that if an inventor assigned a patent to a firm, he or she was employed by that firm. The application date for their first patent for that firm is also noted.

There are a number of limitations with finding inventors in this way, primarily due to Google Patents not being fully reliable. Since the majority of the patents are searchable only through OCR, many patents could have been missed. This is because OCR frequently scans words incorrectly. This problem is inherent to any scanned document search, and is unavoidable without an improvement in the technology. Similarly, a firm's name is sometimes split onto two lines with a hyphen. This can be worked around relatively easily by searching accordingly. For example, several patents were found by searching for "Fair-child camera and instrument."

A second issue is that if there is a sufficiently large number of patents found for a particular search, Google Patents appears to truncate the results. This has been observed to happen in the range of 600-700 patents. Accordingly, this problem was only an issue for the largest firms – RCA and Philco. The Silicon Valley firms, Motorola, and Mostek were too small for this ever to become a problem. TI was searched year-by-year, so the number of patents was also never high enough. Because of this, the list of inventors for RCA and Philco can be considered a sampling at best.

The final problem with this stage is the use of class-based sorting for RCA. In the early years of the industry, many semiconductor inventions did not fall within the five classes which would later become dominant, particularly processes for growing and working with semiconductive materials. For example, from 1953 to 1960, 35 of Texas Instruments' 141 semiconductor patents were not in any of the five classes. This again suggests that the list I have compiled for RCA is an incomplete sampling. However, it may be noted that a great deal of the inventors in this sample were tracked.

Previous Patents

The first step in tracking inventors is searching for patents they applied for prior to their work at one of the semiconductor firms. These patents are of great value because every patent lists the inventor's name, location, application date, issue date, and usually an assignee firm. In the best cases, this allows pinpointing of an inventor's former employer and home city/region. Both of these are important, and the existence of previous patents eliminates a great deal of guesswork when ascertaining an inventor's origins. Having the previous patents can also give an idea of what sort of work the inventor was involved in with his former employer, in particular, whether it was semiconductor-related or not.

The time frame (based on application dates) set for the Google Patents search was January 1940 to December of the application year of the earliest patent I had on record for each inventor. In some cases, the previous patent search unearthed unrecorded patents for the original firm; these were added to the database. One difficulty with this is that it is frequently unclear whether two patents granted to the same name are actually the same person, particularly with common names. Frequently, only middle initials are listed, which can add to the ambiguity. In some cases, use of middle initial or full name is not consistent. Patents applied for significantly before the first semiconductor patent were generally thrown out if they were unrelated to electronics.

Biographical Searches

Many of the inventors found in the initial patent search were and are notable scientists or engineers in their fields. There are many publications which list biographical information about such people.

This stage begins with the Biography and Genealogy Master Index (BGMI). The BGMI is a database of citations for names. A user can search for a name and the BGMI lists all publications it has on record in which that person appears. A similar difficulty exists here as in the previous patent search – people with common names are hard to identify.

Typically, BGMI searches resulted in one of three main sources: *American Men and Women of Science*, Marquis *Who's Who*, and *Leaders in Electronics*. *American Men and Women of Science* is a series of books which publishes information about notable scientists, including date of birth, education, employment history, marriage and family history, and current activities. Editions 12 through 27 were used. Marquis *Who's Who* contains similar information, with a more variable level of completeness for each entry and a wider focus. Searches for *Who's Who* entries were done through Marquis's online database. *Leaders in Electronics* (1979) is a single volume similar to *American Men and Women of Science*, but focused on the electronics industry. On some occasions, other sources found through BGMI were used, but this was relatively rare.

Using these sources, I created a database containing date of birth, date of death, educational history, and years spent at each semiconductor firm. Further, all information on previous employment was recorded, including firm, years, position, and location (if given).

In some cases, biographical sources revealed that an inventor I had recorded patenting for one firm worked at another semiconductor firm I had searched, but did not record any patents. These people were added to the other firm's list. A notable example is Intel co-founder and CEO Andy Grove. Grove assigned a patent to Fairchild, his original employer. He did not patent for Intel, but because his involvement with Intel is known, he was included in their list, as well.

Web Searches

The final step in gathering information is the web search. For any inventor whose profile was incomplete, I conducted a Google search for his or her name. Unless the name was particularly uncommon, I included the semiconductor firm's name in the search.

These searches turned up a wide variety of sources. This included obituary sites, personal web pages and résumés, university web pages, and university alumni newsletters. There were several particularly notable websites that were especially useful. The Computer History Museum has brief biographies of many notable names in the early history of computers as well as interviews. The Transistor Museum also has a number of interviews. The Institute of Electrical and Electronics Engineers maintains a database of scanned electronics papers called IEEE Xplore. Many papers in this database have biographical information about their authors. Lastly, LinkedIn, a social networking site, provided a great deal of information. Users of the site enter whatever educational and employment information they choose, so it is often incomplete. LinkedIn is particularly useful for the "younger" firms, such as Intel and Mostek, whose employees are much more likely to still be working in the industry and maintaining a presence on such websites.

Inventor Categorization

Using a combination of the above sources, I formulated a "best guess" for the activity and location of each inventor prior to working for a given firm. It must be noted that inventors who worked for multiple firms are counted multiple times. Their time spent at each firm is considered a separate observation. In total, 485 observations were considered complete enough to include in the final dataset.

Table 1 gives a summary of tracking success for each firm. The number of inventors tracked only with previous patents (no biographical sources or web pages) is given, as well. Note that the number of total patents is not equivalent to the number of total inventors. Many inventors were granted multiple patents for a particular firm, some patents have multiple inventors, and not all inventors were granted patents for every firm they worked for.

Table 2: Tracking Statistics

Firm	Total Inventors	Inventors Tracked	Patents Only	Percent Tracked	Percent Patent Only
Shockley	23	21	2	91.3%	9.5%
Fairchild	177	108	35	61.0%	32.4%
Rheem	46	30	14	65.2%	46.7%
Signetics	79	52	21	65.8%	40.4%
Amelco	19	10	5	65.8%	50.0%
National	73	33	16	45.2%	48.5%
Intel	65	47	11	72.3%	23.4%
RCA	45	36	9	80.0%	25.0%
Philco	96	46	27	47.9%	58.7%
TI	100	40	7	40.0%	17.5%
Motorola	137	57	26	65.8%	40.4%
Mostek	52	25	6	48.1%	24.0%
Total	912	485	179	55.4%	35.4%

Notes: "Percent Patent Only" indicates the percentage of tracked inventors who could only be tracked using prior patents.

I then classified the inventors into categories, based on their origins:

<u>Worked for the firm previously</u>

> For diversified firms only, this category indicates that the inventor worked at that firm doing work unrelated to semiconductors before patenting semiconductor devices or processes.

<u>Worked for the parent firm</u>

> For spinoff firms only, this category indicates that the inventor worked for the parent firm before moving to the spinoff.

Worked for an affiliated firm

Following Rheem's buyout by Raytheon, Raytheon brought in employees from its other operations, mostly in Massachusetts. Similarly, Corning Glass Works helped to finance Signetics, and many Corning employees from New York went to Signetics. This category indicates one of these moves.

Worked for a local firm

This category indicates the inventor was employed by a firm in the same area as the semiconductor firm. For the Silicon Valley firms, this is defined as the San Francisco Bay Area and the surrounding area, mostly Santa Clara county. For the Texas firms, this is generally defined as the state of Texas. This wider view is supported by Leslie and Kargon's argument that TI, being the only semiconductor firm in the state (for a time, at least), could capture most of the talent in the state. For the east coast firms, this is defined as the Philadelphia metropolitan area, New Jersey, and New York City. Location published on previous patents, as well as knowledge about where firms have been historically based, was used to determine this.

Worked for a non-local firm

This category indicates the inventor was employed by a firm outside the semiconductor firm's region.

Worked for a semiconductor firm

This category indicates the inventor previously worked for a different semiconductor firm, excluding the parent firm. When the inventor's previous employer was diversified, patents were used to determine the nature of the inventor's work at that firm. When this information was not available, an educated guess had to be formulated.

Worked for a non-semiconductor firm

This category indicates the inventor's previous employer was not involved in semiconductors or the inventor was not involved with semiconductors at a diversified firm.

Worked for a local research institution

Research institutions include universities, government research laboratories, and private laboratories. Some examples are Stanford Research Institute, NASA, U.S. Navy laboratories, Oak Ridge National Laboratory, and California Research Corporation. It also includes university professors who consulted for semiconductor firms. This category indicates the research institute was in the same region (as defined above) as the semiconductor firm.

Worked for a non-local research institution

This category indicates the inventor's prior research institute was not in the same region as the semiconductor firm.

Attended a local university

This category indicates the inventor was a recent graduate of a local (as defined above) university. This includes all levels of degree – bachelor, master, and PhD. This also requires that the inventor did not hold another job between completion of the degree and working for the semiconductor firm.

Attended a non-local university

This category indicates the inventor was a recent graduate of a university in a different region.

Worked for the U.S. government or military

This category indicates the inventor worked for the government or military in any capacity, including active military service and work for government or military laboratories.

Table 3 summarizes the total number of inventors in each category, the percentage out of the total, and the percentage of Silicon Valley inventors in each category.

Table 3: Summary of Inventor Origin Categories

Category	Inventors	Percentage	S.V. %
Worked for firm previously	57	11.8%	0.0%
Worked for parent firm	67	13.8%	21.1%
Worked for affiliated firm	16	3.2%	5.6%
Worked for local firm	43	8.9%	11.9%
Worked for non-local firm	171	35.3%	37.2%
Worked for semiconductor firm	113	23.3%	29.5%
Worked for non-semiconductor firm	102	21.0%	19.6%
Worked for local research institution	17	3.5%	5.6%
Worked for non-local research	14	2.9%	1.8%
Attended local university	43	8.9%	8.4%
Attended non-local university	64	13.2%	11.6%
Worked for government or military	9	1.9%	1.1%

Notes: Some categories are not mutually exclusive. S.V.% refers to percentage of Silicon Valley inventors in each category.

Additionally, several other categories were created. In order to address claims about the specific influence of Stanford and Berkeley, individual categories were created for these. Similarly, categories were created for major semiconductor firms RCA, Bell Telephone Laboratories, TI, and Motorola. Additionally, many combinations of pooled categories, such as for all local inventors (combining local researchers, firm employees, and graduates) can easily be created.

Empirical Results

The method will use logistic regression to determine the effect region, time period, and firm type have on the likelihood the firm will hire an inventor from a particular category. This will be used to assess the validity of the hypotheses made earlier. For explanatory variables, I categorize the firms as seen in Table 4.

The most important of these categorizations is the region. This allows comparisons between the Silicon Valley firms as a whole and the other firms. This is critical for the testing of the hypotheses.

Table 4: Explanatory Variable Summary

Firm	Region	Type	Parent
Shockley	Silicon Valley	Startup	
Fairchild	Silicon Valley	Spinoff	Shockley
Rheem	Silicon Valley	Spinoff	Fairchild
Signetics	Silicon Valley	Spinoff	Fairchild
Amelco	Silicon Valley	Spinoff	Fairchild
National	Silicon Valley	Spinoff	Fairchild
Intel	Silicon Valley	Spinoff	Fairchild
RCA	East	Diversifier	
Philco	East	Diversifier	
TI	Texas	Diversifier	
Motorola	Arizona	Diversifier	
Mostek	Texas	Spinoff	TI

Note: "East" refers to the Philadelphia, New Jersey, and New York region.

I now present quantitative analyses of the five hypotheses, in order.

Local Hires

In assessing the prediction that Silicon Valley firms are more likely to hire from local firms, I regress the probability that an inventor was already in the region prior to hiring. Table 5 shows estimates for these regressions. For these regressions, any inventors who worked for the firm previously (but not in semiconductors), worked for the parent firm, or worked for an affiliated firm have been removed, focusing on fully new hires only. Inventors falling into one of those three categories will be referred to as "associated" inventors. For all regressions, Silicon Valley is the base variable.

In regression (i), the dependent variable is the probability the inventor worked for a local firm. In (ii), local researchers are added, and in (iii), local graduates are added. Regression (iv) eliminates Signetics, Amelco, National, Intel, and Mostek to gauge only the earliest firms. The purpose is to assess the possibility that Silicon Valley had an advantage in terms of local hiring from the beginning.

Table 5: Logistic Regression Coefficient Estimates for Local Hires
(Standard errors in parentheses)

	(i)	(ii)	(iii)	(iv)	(v)
	Firm	Firm and Research	Firm, Research, and Grad	Firm	Firm and Research
Texas	-2.293	-2.775	-.3763	-1.167	-1.848
	(1.027)	(1.023)	(.3447)	(1.063)	(1.044)
Arizona	-2.233	-2.714	-2.108	-1.542	-2.223
	(1.028)	(1.023)	(.6133)	(1.059)	(1.039)
East	.2521	.2406	.0961	.9432	.7324
	(.4623)	(.4078)	(.3787)	(.5276)	(.4468)
Constant	-1.638	-1.157	-.6222	-2.329	-1.649
	(.1874)	(.1621)	(.1451)	(.3158)	(.2442)
Observations	345	345	345	242	242

For regressions (i), (ii), and (iii), coefficients for the eastern firms (Philco and RCA) are clearly insignificant. This, however, means little, as the number of eastern inventors who were not associated was relatively low. In the first two regressions, the coefficients for Texas and Arizona are negative and significant. This implies that firms in both regions hired much more from outside the region when not hiring from parents or from within their own firm. This supports the argument that firms in Silicon Valley took advantage of a large pool of local labor.

When we consider regression (iv), Texas and Arizona have lost significance, suggesting that the early Silicon Valley firms may not have had much of an advantage in hiring from local electronics firms. However, when local researchers (many of which were affiliated with Stanford) are included, Texas and Arizona are more significant, particularly isolated Motorola in Phoenix.

Semiconductor Hires

The following regression estimates the probability that an inventor worked at another semiconductor firm immediately before being hired. Associated inventors are again excluded. For comparison, regression (ii) estimates the probability that an inventor is hired from any firm. Silicon Valley is the base variable for both regressions.

Table 6: Logistic Regression Coefficient Estimates for Semiconductor Hires
(Standard errors in parentheses)

	(i)	(ii)
	Semiconductor Firms	All Firms
Texas	-.6010	-.8401
	(.3430)	(.3144)
Arizona	-.8422	.4400
	(.3703)	(.3631)
East	-1.650	-1.212
	(.5497)	(.3793)
Constant	-.3975	.6860
	(.1411)	(.1466)
Observations	345	345

First consider Texas (TI and Mostek) and the eastern firms (RCA and Philco). They are all less likely to hire semiconductor firm employees and less likely to hire employees from all firms than the Silicon Valley firms. In Arizona, Motorola was less likely to hire from semiconductor firms when they hired from firms at all. The finding that Silicon Valley firms are more likely to hire from other semiconductor firms is important. It shows that semiconductor inventors drifted toward Silicon Valley, contributing to the agglomeration of the industry there.

Reliance on Parents

Four different methods are used here to estimate the likelihood a spinoff firm hires an inventor from its parent. The explanatory variables are periods, defined in two different ways:

A) Period 1: Fairchild, Rheem
   Period 2: Signetics, Amelco
   Period 3: National, Intel, Mostek
B) Period 1: Fairchild
   Period 2: Rheem, Signetics, and Amelco
   Period 4: National, Intel, Mostek

Regression (i) uses scheme A, while the rest use scheme B. A comparison of the coefficients in (i) and (ii) reveals it makes little difference which one is chosen; I have taken scheme B arbitrarily for (iii) and (iv). One possible problem is Fairchild's relative longevity and size compared with its parent, Shockley Semiconductor. This could possibly skew the coefficients upward. To control for this, regression (iii) excludes all Fairchild inventors who did not apply for a patent before 1970. This date was chosen arbitrarily. Regression (iv) adds in the three members of the "Traitorous Eight" who did not assign any patents to Fairchild. Period 1 is the base variable in all four regressions.

Mostek has been included as an explanatory variable to ascertain whether being in Silicon Valley has any effect on hiring from a parent.

Table 7: Logistic Regression Coefficient Estimates for Parent Hires
(Standard errors in parentheses)

	(i)	(ii)	(iii)	(iv)
	Parent	Parent	Parent	Parent
Period 2	1.598	1.602	1.255	.8979
	(.3775)	(.4031)	(.4654)	(.4168)
Period 3	.8641	1.126	.7789	.4223
	(.3720)	(.4218)	(.4817)	(.4349)
Mostek	.1373	.1373	.1373	.1373
	(.5151)	(.5151)	(.5151)	(.5151)
Constant	-1.946	-2.208	-1.861	-1.504
	(.2673)	(.3332)	(.4063)	(.3496)
Observations	290	290	241	244

Based on (i) and (ii), both Period 2 and Period 3 exhibit a higher reliance on the parent for hiring when compared with Period 1. Even with the later patentees removed, the coefficient for Period 2 remains positive and significant. Period 3, however, ceases to be significant. The lower coefficient on Period 3 is because National Semiconductor is in Period 3. National was an anomaly in terms of hiring from the parent; Intel and Mostek hired a great deal from their parents, yet National did so very little. The coefficient on Mostek is not significant, so it does not indicate any major differences between Silicon Valley and Texas on this issue.

University Impact

Here I assess the role of universities, and in particular direct effects of local research universities and institutions. Regressions (i) and (ii) estimate the likelihood a new hire will be from any university or a local university, respectively. By including both research employees and graduates, regression (iii) is a way to judge the impact of all research in an area on hiring. Silicon Valley is the base variable for all regressions.

Table 8: Logistic Regression Coefficient Estimates for University and Research Hires (Standard errors in parentheses)

	(i)	(ii)	(iii)
	Graduate	Local Graduate	Local Graduate and Local Research
Texas	.9527	.9437	.3736
	(.3189)	(.3868)	(.3662)
Arizona	-.3314	-1.115	-1.685
	(.3877)	(.7549)	(.7435)
East	.7419	-.0054	-.3195
	(.3760)	(.5739)	(.5146)
Constant	-1.030	-2.042	-1.472
	(.1571)	(.2170)	(.1775)
Observations	345	345	345

In (i) and (ii), Texas has a positive and significant coefficient, meaning the two Texas firms were more likely to hire from universities than the firms in Silicon Valley. This makes sense because there were very few semiconductor firms in Texas other than TI and Mostek. Not only were they more likely to hire Texas graduates who did not have many other options, there were less nearby firms from which to draw new inventors.

Looking at complete local research and universities, the only region which shows significance is Arizona, highlighting again the serious lack of high-quality electronics research in the area, especially when compared with the San Francisco area. Note that in regression (iii), the difference between Silicon Valley and Texas is not significant.

Diversifier Strategy

To verify the two large diversifiers, Philco and RCA, had a greater propensity to transfer their own non-semiconductor inventors over to work on semiconductors, Table 9 shows a simple logistic regression of probability an inventor worked for the firm before working in semiconductors on each of the individual diversifiers. Motorola is the base variable.

Table 9: Logistic Regression Coefficient Estimates for Transferred Inventors
(Standard errors in parentheses)

	Firm Previously
Philco	2.834
	(.6599)
RCA	3.531
	(.6987)
TI	1.059
	(.7415)
Constant	-2.793
	(.5948)
Observations	175

It can be seen that Philco and RCA did indeed transfer inventors significantly more than Motorola. TI was not found to be significantly different from Motorola in this regard, though it did transfer a bit more.

Inspection of previous patents revealed Philco and RCA's inventors were typically involved in color television, refrigerators, air conditioning, washing machines, radio communication, and other consumer goods, as well as general electronics and circuitry.

Discussion

The results of this study do not fully corroborate the hypotheses outlined, but certainly do support some of them. It was shown that, overall, Silicon Valley firms are more likely to hire locally than the more isolated, non-clustered firms in Arizona and Texas. However, looking only at the earliest Silicon Valley semiconductor firms reveals the difference is not significant. This implies that the region did not have special features that made it especially prime for semiconductor clustering before Shockley arrived.

Silicon Valley firms were also more likely hire inventors from other semiconductor firms (excluding parents). This suggests Silicon Valley was extracting talent from other areas that might have otherwise become industry centers, such as TI, Motorola, and Bell Labs. The hypothesis on spinoffs' reliance on parents for labor was not supported. There are, however, limitations with the method used, one being that an inventor's earliest patent application date may not accurately reflect his hiring date.

One of the most interesting results was on the impact of universities. Contrary to the popular argument that Silicon Valley was greatly aided by the presence of Stanford and UC Berkeley, it was shown that Texas hired the most from universities, especially ones located in Texas. However, once research employees are factored in, the influence of Stanford can be felt, and Texas's advantage loses significance.

The final conclusion that can be made is that the data show a major difference in the hiring patterns of the diversifiers. RCA and Philco drew heavily on their established employees from other divisions to work on semiconductors. Motorola and TI took different routes – Motorola hired from other firms, establishing their new operation in Phoenix. TI hired from other firms and from universities to establish itself in semiconductors. Currently, over 50 years later, TI is still an industry leader and Motorola's semiconductor division, now spun off into an independent firm (Freescale Semiconductor), remain players as well. In contrast, RCA and Philco fell away relatively quickly. The data collected for this analysis cannot make a judgment on why this may have happened, but it seems that bringing television and refrigerator engineers into semiconductors was not a successful strategy.

Limitations

There are many limitations and possible issues with the analysis presented. One is the large mass of untracked inventors. Of 912 inventors, only 485 could be tracked. There is no reason to believe that the inventors who were tracked are a representative sample; in fact, they are the more notable inventors, and for that reason alone they are not representative. Additionally, the data for RCA and Philco suffered from small sample size. Since most of those firms' inventors came from inside, the non-associated inventors were few in number, making inaccurate estimates a possibility.

Another potential issue is ambiguity in some tracked backgrounds. In some cases, a former employer was found, but not a location. Educated guesses had to be made on whether this firm was local or not. The same issue exists when it was unclear whether an inventor worked on semiconductors at his previous job.

Finally, human error undoubtedly crept into the data. The data collection was a multi-stage undertaking, done by one person. With 485 inventor observations and nearly 1000 patents, it is unlikely that every mistake was corrected.

Extensions

The main way this project could, and ideally should, be extended is to include more inventors. This would be done in two ways. Recording more firms would add more regions to study with unique features. Also, bringing the analysis of the already included firms into later time periods would provide even more opportunity for comparison. Going further into the future would be especially useful for studying how spinoff behavior changes as the industry develops, and how parent firms react through their own hiring, as they must replace inventors who are lost to the spinoff.

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