The Exploration of Technological Diversity and the Geographic Localization of Innovation

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ABSTRACT. This paper examines the innovative ability of small firms in the semiconductor industry regarding their exploration of technological diversity and their integration within local knowledge networks. Through the analysis of patent data, we compare the innovative activity of start-up firms and larger firms. We find that small firms explore new technological areas by innovating in less 'crowded' areas. The analysis of patent citation data reveals that small firms are tied into regional knowledge networks to a greater extent than large firms. These findings point to the role of entrepreneurial firms in the exploration of new technological spaces and in the diffusion of their accumulated knowledge through local small firm networks.

1. Introduction

Why should geographic space matter to the evident role played by small firms in exploring new technological opportunities? Despite the confusing array of findings regarding the relationship between size and innovation, the evidence is reasonably strong that small firms are more productive in the generation of innovations than larger firms. Though, as an aggregate they spend considerably less on R&D, they produce new innovations with twice the productivity of larger firms (Acs and Audretsch, 1990). Bound et al. (1984) similarly found higher rates of research productivity for smaller firms as measured by patents. However, these results are influenced by variations in technological opportunities among industries and in geography. The higher productivity of small firm research is evident in only some industries and is more conclusive for the United States than for other countries (Scherer, 1984; Pavitt et al., 1987).

These findings on small firm innovations suggest a sea change in our understanding of the perennial question of the relationship between firm size and innovation. The evidence points to the role played by the birth of startups in fields of high technological opportunity as an important driver of radical innovation. The lack of robustness of the relationship between firm size and innovation is not surprising in the light that size is a moving target driven, partly, by a firm's research success. Based on varying interpretations of Schumpeter's reflections on the routinization of research in the large laboratory, most studies have sought a cross-sectional relationship between firm size and innovation. But the cross-sectional evidence, as Cohen and Levin (1989) conclude in their review, is very mixed. There appears to be no hard and fast statement regarding optimal firm size or scale economies in reference to innovative activities.

The change in perspective extends beyond seeing size and innovation as linked in a dynamic process. There is a broader way to understand the relationship, as first suggested by Jewkes, Sawers, and Stillerman. "It may well be," they note, "that there is no optimum size of firm but merely an optimal pattern for any industry, such a distribution of firms by size, character and outlook as to guarantee the most effective gathering together and commercially perfecting of the flow of new ideas" (1969, p. 168; cited in Cohen and Levin,

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1989, pp. 1073–1074). This line of inquiry presents the important questions why, in some industries and in some countries, are small firms more productive in the generation of new knowledge and how can larger firms be viable if they are inefficient. Cohen and Klepper (1996) propose that these two questions are linked. Small firms may be superior in the generation of new knowledge in industries characterized by technological opportunities. Larger firms are superior in their ability to appropriate returns from these innovations, either by buying and selling property rights (sometimes through cooperative ventures), acquiring the firms or benefiting through spill-overs.

If the focus is shifted from the optimal size of firms to "effective" size distributions, a puzzle concerns what sustains the viability of small firm innovative activity? In this paper, we argue that when small firms are understood as start ups, they can be seen as playing two important roles in the exploration of technology and local networks. In many industries, start ups receive funding because they explore new technological spaces and opportunities that are ignored by larger firms. Since their technological exploration is facilitated through close ties to other innovating institutions and start up firms, their activities also, however, generate a geographic space in which knowledge of their research diffuses more rapidly within a local network of firms. As long as this technological space is sufficiently rich, the interaction of diffusion and innovation creates a positive feedback that reinforces further innovative efforts. This combination of the exploration of technological diversity and local firm networks contains the answer to two questions: why are small firms in high technological opportunity industries more productive in their research and why does innovative activity appear to have a spatial character.

We analyze the technological activity of small and large firms through the examination of patent data in the semiconductor industry. A statistical analysis of the technology classes in which small and large firms patent shows that while large firms dominate patenting in well established areas, small (start up) firms produce important innovations in smaller, less crowded fields. The examination of patent citation data indicates that start ups are integrated into local knowledge networks to a greater degree than larger firms. Thus, we suggest there is a common explanation to why small firms are productive and the diffusion of innovations has a spatial character: the generation of new knowledge is facilitated by small firm networks.

2. Technological diversity and start up networks

The conventional explanation for the role played by small firms in high innovation industries has appealed to the deficiency of internal incentives and flexibility in larger companies. (Monopolistic motivations are pertinent in industries less characterized by the potential for the introduction of radical innovations.) The attention paid to Schumpeter's discussion on the routinization of innovation often neglects the other side of the equation, namely, his earlier emphasis on the dynamic role played by new firm innovations. His pessimism over the supply of entrepreneurs (1943, p. 152) led him to characterize the process of 'creative destruction' increasingly driven by large firms that are capable of innovating within a 'routinized' regime.

There is substantial qualitative evidence supporting the role of small firms and individuals in introducing 'radical' innovations. While examining 50 important and successful innovations introduced this century, Jewkes, Sawers and Stillerman (1958) found that a critical role was played by the individual inventor – more than half of these innovations were introduced outside established research organizations. Scherer and Ross (1990) highlight several 'revolutionary' inventions by start-up firms that departed significantly from the technologies in use at the time of the invention. Among the inventions mentioned are the incandescent lamp (Edison), the FM radio (Armstrong), the microwave oven (Raytheon), the microcomputer (Altair and Apple) and the microprocessor (Intel). They point out that invitations to collaborate with the inventors of these technological breakthroughs were often turned down by larger firms.

The drawback to large firm research is that innovation in large firms becomes routinized and results in a reluctance to explore new technological fields. A wide variety of organizational studies support the idea that 'inertia' within an organization increases with age and size (Hannan and

Freeman, 1984; Downs, 1967). This inertia perpetuates innovation along established directions but prevents them from exploring new opportunities and hence developing ‘radical’ innovations. Smaller firms are more likely to possess the organizational characteristics permitting the adjustments necessary to take advantage of new opportunities. Further, a range of factors including financing, government regulations, and the motives and goals of the entrepreneurs provide the conditions for small firms which are more amenable to the exploration of diversity (Nooteboom, 1994). Hence small firms are better equipped to exploit new technological opportunities through the exploration of diversity. Some support for the link between new entrants and radical innovation is provided by Henderson (1993). In a study of the photolithographic alignment equipment industry, Henderson shows that larger incumbent firms were less productive than start-up firms in exploiting radical innovations.

However, as early Schumpeter (1934) noted, start up companies are hampered by limits to financial and human resources to support their activities. Small firms rely on regional knowledge networks for important inputs to the innovative process. The presence of spatially concentrated mutually supportive networks has been well documented in many regions of the world. Localized information sharing was common among geographically clustered firms in the steel industry in nineteenth century England (Allen, 1983). Case studies of regional clusters of small and medium sized firms in Italy (Piore and Sabel, 1984) and Baden-Wuerttemberg in Germany (Herrigel, 1993) indicate extensive interdependencies between the located in these regions.

More recent statistical studies have conclusively found that innovations have a strong regional character. In a recent study, Jaffe, Trajtenberg, and Henderson (1993) analyzed patent citation data pertaining to domestic university and corporate patents to test the extent of localization of knowledge spillovers. They found evidence that patents tend to be cited in the same area where the originating patents are located, even after controlling for the existing concentration of patenting activity. Similarly, Almeida and Kogut (1995) studied the spatial diffusion of technological knowledge through the analysis of important semiconductor innovations and through field interviews with engineers and scientists in the industry. Their findings indicate that knowledge remains localized in the U.S. and particularly in Silicon Valley.

The presence of a local networks holds several advantages in resource acquisition for small firms. One of the advantages of regional networks for small firms is that locational proximity reduces the cost and increases the frequency of personal contacts and serves to build social relations. Professional relationships are often embedded in these social networks.

Local social and professional networks decrease the uncertainty and costs associated with start-up activity, which encourages the provision of venture capital. The flow of information that serves as a common stock of knowledge in the region for innovations also sets the foundations for the exploration and exploitation of new knowledge by startups.

But why should this phenomenon of regional networking benefit smaller firms rather than larger firms? One reason is that larger firms are more self reliant and fail to build relationships with other institutions within the region. By definition of a start up, the personnel in a new company will have, on average, a short tenure in the company and, hence, recent employment experiences in other firms or research institutions.

More intriguing is that the paucity of resources in a small firm creates an incentive to rely upon outside sources of knowledge. In a rich ethnography of regions in the semiconductor industry, Saxenian (1994) contrasted the industrial systems of the Route 128 region (around Boston) and the Silicon Valley area (near San Francisco) to explain the comparative success of the Bay Area. She noted that the Silicon Valley region with its greater share of start-up firms is characterized by local collective learning and experimentation resulting in extensive inter-firm knowledge exchange. The Route 128 region is dominated by larger firms which are more insulated from the surrounding institutions. These firms did not build relationships with other firms in that region and this, in part, contributed to the decline of that region in recent years. Statistical studies have confirmed the importance of external sourcing of resources by small firms. Feldman (1994) uses Small Business

Administration innovation data to ascertain the importance of inputs to innovation for firms of different sizes. She finds that although large firms benefit from local innovation, for small firms the benefit are significant – small firms are two times more sensitive to local university research.

We seek to establish two important facts about innovations and startups. First, startups are unusually oriented toward the exploration of diversity by targeting less crowded technological fields. Second, their exploration has a strong local character: they are more sensitive to, and contribute more to, the innovations of spatially-contiguous firms. To establish these facts, we analyze patenting and citations in the semiconductor industry.

3. Research setting: the semiconductor industry

Insight into the evolution of "optimal size distributions" of an industry can be gleaned in the history of the early entry and growth of startups into the semiconductor industry , and their subsequent relationships to a second wave of entry that commenced in the late 1970s. Technological innovation, start up firms and regions have all played a vital part in the development of the semiconductor industry over the last five decades. The industry originated from the invention of the first solid state transistor at the laboratories of AT&T (Bell Labs) in New Jersey in 1947. The industry has been characterized by waves of start-up activity each resulting in the exploration of new fields and the discovery of major innovations. Ever since William Shockley left Bell Labs to start Shockley Semiconductors in Palo Alto, California, entrepreneurship and hence start-ups have played an important role in the diffusion of knowledge and the evolution of the industry (Moore, 1986). Several of Shockley's assistants left his firm and formed Fairchild Semiconductors in 1957. The newly formed Fairchild was the source of one of the most important innovations in the semiconductor industry. In 1959, Robert Noyce of Fairchild, developed the 'planar process' which permitted large scale production of integrated circuits. This important advance helped launch the era of the Integrated Circuit. Fairchild itself spawned a host of new spin-offs. In fact, the origins of almost every firm in Silicon Valley can be traced back to Fairchild. Several of these start-ups, via successful innovation, grew into large firms, often dominating sections of the industry.

The most striking example of the process of growth through innovation is the case of Intel. Intel, one of the 'Fairchildren', was started by a group of entrepreneurs in the late 1960s. Within a few years of its formation Intel introduced both the memory chip and the microprocessor – the two types of integrated circuits that came to dominate the semiconductor industry. With the growing popularity of the personal computer in the 1980s and 1990s, the demand for memory and microprocessor chips exploded. Though Intel dropped out of the memory market, the firm continued to dominate the microprocessor segment. Even today, Intel produces 70% of the worlds microprocessors making it the largest semiconductor manufacturer in the world.

Though larger firms came to dominate more established fields (the memory segment is dominated by large Japanese firms), new waves of start-ups continue to bring about technological changes. In the 1980s, small firms dominated innovation in the areas of Application-specific Integrated Circuits (ASICs), high performance CMOS memory and logic chips. As ASICs grew more popular over the last decade, many of the start-ups of the 1980s have grown rapidly. A new wave of start-ups in the middle 1990s are investigating new and emerging fields such as three-dimensional integrated circuits, voice recognition and synthesis, bioelectronics and optoelectronics. While semiconductor start-ups continue to drive new design technologies, larger firms dominate in the manufacture of integrated circuits and the development of more mature segments of the industry. Thus, though innovation is driven by firms of all sizes, the entry and growth process of new firms continues to play an important role in new technology development.

Another remarkable aspect of the semiconductor industry is the role played by regional networks. Technology diffusion within regions has been facilitated by the culture of networking and information exchange between engineers. Managers within the industry are known to actively seek outside information useful in various stages of innovation (Saxenian, 1991). Engineers at different companies share problem solving information by discussing failed avenues of exploration; solutions are less likely to be communicated (Rogers, 1982). Many of these conversations take place at social occasions. In their history of the semiconductor industry, Braun and MacDonald (1982), provide the example of a bar located close to Intel, Fairchild, Raytheon and other semiconductor companies, which served as a place where engineers 'drank, exchanged information and hired employees'. Thus the prevalence of start-ups and the culture of networking make the semiconductor industry a good candidate for the study of innovativeness of small firms.

4. Data and methods

The research design is broken into two parts. The first part is oriented toward establishing that small (mostly start up) firms are more active in the less crowded technological fields. The second part is designed to analyze whether the diffusion of small firm research activities is more localized than that of larger firms.

Two types of data are used for the analysis: (a) Patent data relating to important semiconductor design innovations, and (b) Semiconductor plant location data used to identify relevant regions. By plotting the location of semiconductor plants throughout the U.S., 18 main regions of semiconductor activity were identified. The most important regions in terms of both number of plants and employment were in the Silicon Valley area and the New York-New Jersey-Pennsylvania area (NY-NJ-PA). Other important regions of semiconductor activity included the Boston 128 corridor, Texas (Austin), California (Los Angeles) and Arizona.[1]

In this paper, we use U.S. patent data to (a) examine the areas of technological exploration of small and large firms in the semiconductor industry and (b) to the examine geographic patterns of knowledge dissemination for these firms. The geographic characteristics of spillovers are analyzed using patent citation data relating to major patented innovations. This analysis is carried out using the case-control method. The case-control study seeks to investigate the extent to which citing patents and comparable patents (controls) differ with respect to their geographic characteristics.

Identification of major innovations

Patent citation data are first used identify important inventions. (Appendix A describes patent citation data and their applicability to the semiconductor industry.) Several studies (Albert et al., 1991, Carpenter et al., 1981 and Narin et al., 1987) have shown that patent citation counts are a good indicator of the technological importance of an invention. Further, Trajtenberg (1990) in his study of CT scanners, showed that the number of citations to a patent serves as an indicator of social and economic value of the innovation. Highly cited patents tend to be of both technological and economic importance.

We first identified highly cited patents from over 400 technical classes and over 100,000 subclasses which make up the U.S. patent classification system. Since this study is concerned with patents related to semiconductor devices, the relevant classes and sub-classes for semiconductors were identified using the classes specified by the U.S. patent office (U.S. Department of Commerce, 1992). These classes, however, are not exclusive to the industry. A broad scan of the relevant semiconductor classes was undertaken and all highly cited patents (having more than 10 citations) were identified. From this broad set of patents, semiconductor design patents were identified by two electrical engineers through a review of titles, abstracts and when necessary complete patent documents.

In an earlier study, we identified major patents with application years in three distinct time periods (1975, 1980 and 1985).[2] The sample of relevance to this study, is the 1985 sample of design patents which consisted of 20 patents that fulfilled the criteria for selection as a major patent. This sample did not generate any patents belonging to small or start up firms. Curiously, in spite of the apparent innovativeness of start-ups in the semiconductor industry, no major patent identified by the research design belonged to a start-up firm. Given the history of start ups in the semiconductor industry, the result is surprising. However, in the course of the study, it became clear that start ups were frequently active in other technological classes. As a result, we generated a second design oriented toward capturing major patents held by start ups.

We identified all the patents belonging to any of the 176 semiconductor start-ups formed between 1977 and 1989 (Dataquest, 1990). Of the 176 firms, 57 firms had significant (3 or more) patenting records. From these patents, we identified the most highly cited patents filed in the year 1985, thus creating a sample of major patents belonging to start-up firms.

This second method generated a list of 20 major patents belonging to semiconductor start-ups. As a result, we created two samples of major patents. The first sample was drawn by identifying the 20 most highly cited major patents in conventional semiconductor technological fields according the U.S. Patent Office (U.S. Department of Commerce, 1992). The second sample began with start up firms, and then identified their 20 most highly cited patents. An examination of the technology (patent) classes of these innovations revealed that the major innovations were in technological fields not included in the list originally used to identify major semiconductor patents. Apparently, major start-ups innovations belong to different fields than those dominated by larger firms.

In Table I, we report the descriptive statistics for the two samples. The patents from both samples were highly cited (about 15 citing patents per major patent). If, as explained earlier, the number of citations to a patent are an indicator of importance, major innovations from start-ups and ‘Other’ firms play a critical role in technology development.

Citations and controls

Localization is indicated by the joint condition that the citing patent and the major innovation belong to the same geographic region. To measure the frequency of localization, we geographically matched each set of major patents with the citing patents. However, the observed frequency of geographic coincidence of the major patent and the citing patents may reflect the distribution of patenting activity rather than the localization of spillovers.

To adjust for any bias due to this existing distribution of technological activity, we followed Jaffe et al. (1993) in the construction of a control sample. For each citing patent, we identified a corresponding control patent. This patent was identified such that the patent (technology) class was identical to that of the citing patent and the application date was as near as possible to the citing patent. The control patent thus closely resembles the citing patent in terms of technology and time of innovation. Since the control patent, however, does not cite the major patent, the frequency of a geographic matches between the two reflects the existing concentration of patenting activity for a particular region. This frequency of geographic matches between the major patent and the control patent sets the baseline against which we compare the frequency of major patent-citing patent matches.

Statistical test for localization of spillovers

Figure 1 illustrates the design of the statistical test. Let Pcit be the frequency probability that the major patent and citing patent are geographically matched, and Pcon be the corresponding frequency probability for the major patent-control patent match. Assuming binomial distributions, the null hypothesis is

$$H_o: P_{cit} = P_{con}$$

and the alternate hypothesis is

$$H_a: P_{cit} > P_{con}$$

The t statistic is calculated as follows

$$t = \frac{(P_{cit} - P_{con})}{\left[\dfrac{(P_{cit}(1 - P_{cit}) + P_{con}(1 - P_{con}))}{n}\right]^{0.5}}$$

TABLE I
Descriptive statistics

Sample	Number of major patents	Number ofcitations	Mean citations	% self citations
Start-ups	20	298	14.9	11.4
Other firms	20	300	15	16

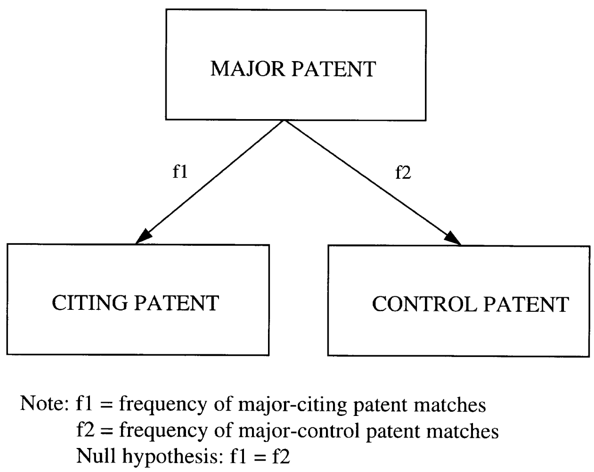

Fig. 1. Test of localization of patent citations.

The '*t*' statistic tests the difference between two independently drawn binomial proportions.

For both samples, Pcit, Pcon and the corresponding '*t*' statistic were calculated. A positive significant value of Student's *t* indicates support of the proposition that spillovers are geographically mediated. The tests were carried out for geographic regions within the U.S. for both samples.

5. Results and discussion

Exploration of technological diversity

To examine whether start-up firms patent in less crowded fields than larger firms, we identified the technology classes in which these firms had produced major innovations. We then plotted the total number of patents granted by the U.S. patent office in a) the technology classes in which the larger firms had their major patents and b) the technology classes in which the start-up firms had their major patents. The results are shown in Figure 2.

The figure reveals that start-ups produce major innovations in less crowded technological fields. Larger firms seem to concentrate in more established fields, which have a larger concentration of innovative activity.[3] For instance, established firms like Intel, Motorola, Toshiba and Siemens dominate patenting in microprocessor and dynamic random access memory (DRAM) technologies. Smaller firms are more active in patenting in the areas of Application Specific Integrated Circuits (ASICs), Gallium Arsenide and analog integrated circuits.

We also applied the Student's *t*-test to test for

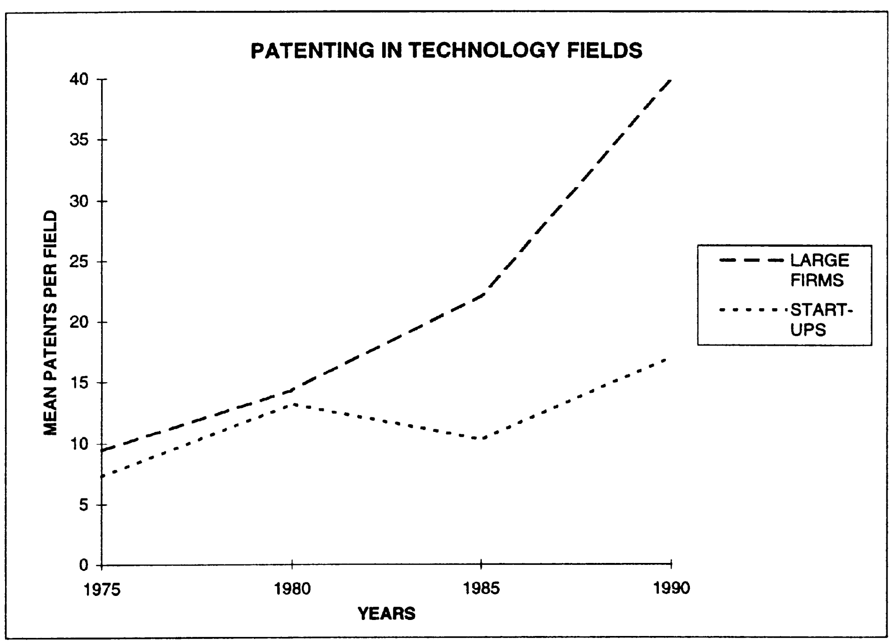

Fig. 2. Patenting in technology fields.

significance in the differences between sample means. Table II reveals significant results for the 1985 and 1990 time periods but not for the 1975 and 1980 period. This analysis provides some support for the proposition that small firms are more likely to explore technologically diverse and uncrowded territories, leaving the domination of more mature technologies to larger firms.

Geographic localization

The sample of major patents belonging to start-up firms is also used to gauge the extent of geographic localization of knowledge pertaining to these patents. Table III compares the extent of localization of knowledge for start-ups and 'Other firms'. The 'Number of Citations' corresponds to the total number of cites for the sample less self cites (when the major and citing patent have the same assignee). 'A' and 'B' are the percentage of citations and controls respectively that belong to the same geographic location as the major patent. The *t*-statistic tests the equality of the control and citing proportions as described previously.

There are a significantly higher proportion of citation matches than control matches indicating significant localization effects. The results confirm the principal findings of Jaffe et al. (1993). Knowledge is localized for both samples but is much more significant for the start-up sample. Start-up firms are more closely tied into regional networks.

The greater localization of knowledge observed for small firms, is not surprising since a large majority of new firms are located in Silicon Valley. Of the 176 start-ups founded around the world between 1977 and 1989, 55% were located in Silicon Valley (Dataquest, 1990). Almeida and Kogut (1995) show that Silicon Valley is unique in terms of its sociology, with extensive inter-firm mobility of engineers, resulting in significant localization of design knowledge. Could the significant localization of knowledge of start-up firms be only due to the characteristics of the region (Silicon Valley) rather than the characteristics of small firms themselves?

To investigate this question, we identified the major patents from both samples that belonged to Silicon Valley and conducted localization tests on those samples (Table IV). Knowledge emanating from start-up firms was more localized than for other firms. Even within Silicon Valley smaller firms appear to be more integrated into knowledge networks than larger firms. We also investigated the role of start-ups as receivers of knowledge. For every major patent belonging to a start-up firm, we identified the citing. Splitting the sample into the two categories (start-up vs non-startup firms), we conducted localization tests to see whether small firms were networked to other small firms locally. The results in Table V indicate significant localization effects for both categories but again localization was more significant for start-up firms.

We then turned to understanding better how start-up firms entered into these regional networks.

TABLE II
Test of technological exploration starts-ups vs other firms

	1975	1980	1985	1990
Other firms				
– mean	9.45	14.35	22.05	39.85
Start-ups				
– mean	7.3	13.2	10.3	17.05
t-statistic	0.54	0.15	2.6	3.15

Note: Mean indicates the mean number of patents per technological field in which either start-ups or 'other' firms have major patents.

TABLE III
Test for localization of knowledge start-ups vs other firms

	Other firms	Start-ups
Number of citations	147	264
A = citation matching %	19.72	33.71
B = control matching %	6.8	10.61
t-statistic	3.33	6.55

Note: Only patents from U.S. regions are used in the analysis.

TABLE IV
Test for localization of knowledge Silicon Valley patents

	Other firms	Start-ups
Number of citations	34	158
A = citation matching %	52.9	53.80
B = control matching %	14.7	17.72
t-statistic	3.64	7.35

TABLE V
Test for localization of knowledge receivers of knowledge

	Other firms	Start-ups
Number of citations	223	41
A = citation matching %	26.91	70.73
B = control matching %	9.87	14.63
t-statistic	4.76	6.23

Much of the start-up activity in Silicon Valley is directed towards the exploitation of new ideas by an individual or a group of entrepreneurs (Rogers and Larsen, 1984). Entrepreneurs use their knowledge of local suppliers, venture capitalists and other firms to further the success of their new firms. Eisenhardt and Schoonhoven (1990) showed that entrepreneurs in Silicon Valley are closely networked with venture capitalists and also with other firms in the region. Since the founders of new firms play an important role in the networking activities of new firms, one would expect that the previous experience in the region that the start-up is located would be an important prerequisite to successful networking activity.

To assess the role played by founders of semiconductor firms, we examined the geographic origins of entrepreneurs. Table VI presents the results of phone interviews of 76 start-up firms (120 firms were contacted, for a response rate of 63%). Over 88% of the founders were employed in the same region prior to the formation of the start-up. As can be seen, previous local experience of entrepreneurs influences the location of start-up activity and therefore the firms networking potential.

TABLE VI
Geographic origins of start-up founders

U.S. region	No. of firms	Matches No.	Matches %
CA-Silicon Valley	44	38	86
CA-LA & San Diego	9	8	89
NY-NJ-PA	3	3	100
TX	2	2	100
MA	4	4	100
OR-WA	4	3	75
CO	5	5	100
Other	4	3	75
Total	75	66	88

Note: a) ‘Number of firms’ indicates the total number of start-up responses per region.
b) ‘Matches’ indicates the number of firms for which the founders had worked in the same region immediately prior to the founding the new firm.

6. Conclusion

This paper offers two reasons for the innovativeness of small firms. Small firms enter as start-ups based on their promise to explore technologically diverse fields and they are tied into local knowledge networks that support their exploration. If successful, start-up firms build upon this knowledge and branch into new fields. However, this subsequent diversification is linked to the richness of the technological opportunities. In fact, Kim and Kogut (1996) found that start ups that began in very narrow technological fields developed little capacity to support subsequent diversification.

We have, consequently, a sketch of an industry that is driven by the exploration of new technological fields. This exploration is frequently carried out by small firms that are linked in dense local networks, to which large firms also belong. When successful, the start-ups prosper and grow. No wonder there is no easy relationship between size and innovation.

There is an interesting policy issue embedded in this discussion. For the financial constraints on small firms often make then vulnerable to acquisition. In fact, in the 1980s 20% of all start-ups involved in ASIC products (application specific integrated circuits) were acquired. The twin conditions of being small and holding knowledge that is local and not internationally diffused would seem to make these start-up firms vulnerable to foreign acquisition.

This question provides an interesting insight into the relationship among small and large firms. Kogut et al. (1993) found that cooperative relationships in the semiconductor industry were structured into national industrial networks. However, American small firms were tightly network with each other and with American large firms. In turn, the American large firm was linked not only to the local small firm network, but also to large companies from other regions, especially from Japan. The cooperative pattern in the U.S. shows, not surprisingly given the above results, a dense national small firm network, with larger firms bridging nations.

An alternative to cooperation is acquisition. Small firms, in regions such as Silicon Valley, are attractive acquisition targets of larger firms seeking technological knowledge inputs. Over the last decade, several firms including Philips, Thomson-CSF, Toshiba, Sony, Samsung and a number of other electronic firms have bought into local knowledge networks by acquiring semiconductor start-ups. Almeida (1996) shows that these foreign firms in U.S. regions use local regional knowledge extensively in their innovative activities.

This discussion, besides its relevance to policy debates over foreign technological acquisition, is important in underlining the problem of focusing solely on the individual firm. Innovation is an activity that shifts the size distribution of firms. It is closely linked to the general progress of science and technology in society. For small firms, innovation is more often than not the product of a firm's efforts to benefit from its own research and from a local network of entrepreneurs and innovators. The difficulty of recreating such networks, as evident in Silicon Valley, is certainly one of the leading candidates why the distribution of innovations varies among regions and countries.

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Appendix

Patent data and the semiconductor industry

This study uses semiconductor patent data to analyze the extent of localization of knowledge spillovers in this industry. Though some firms may choose not to patent innovations, patenting in the semiconductor industry is commonly practiced and is indeed a vital part of maintaining technological competitiveness. Firms may patent for a variety of reasons. The factors that motivate a firm to patent include:

a) Patents establish intellectual property rights which often become an important revenue source (During the late 1980s Texas Instruments earned over a billion dollars from patent royalties)
b) Patent portfolios are used by firms as bargaining chips to prevent or to fight legal battles.
c) Patents facilitate licensing and cross licensing which often serves as an important source of learning for the firm.
d) Interviews with 'headhunting' firms and engineers revealed that patents are valuable to individual engineers and researchers as indicators of personal technological expertise.

Recent government actions have increased the protection for intellectual capital supplied by the patent system and thereby increased the incentive to patent. In 1982, Congress created the U.S. Court of Appeals for the Federal Circuit in Washington D.C., specifically for the purpose of hearing patent cases. This action significantly increased the protection provided by patents.

Notes

[1] Dataquest, a private research firm located in San Jose, California and County Business Patterns (U.S. department of Commerce publication) were the main sources of plant location data.

[2] The major innovations, represented by heavily cited patents, were identified in cooperation with CHI Research, a private research firm. Citing patents and control patents were identified through the use of the on-line patent data base provided in the LEXPAT file on LEXUS.

[3] We used the mean number (for the 20 technological classes) of patents in a given year to capture the extent of patenting in the fields. Ideally we would have liked to produce an indicator of the age of the technological fields in which smaller and larger firms patent, but the patent classification system does not permit this.

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