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# Small Firms and Technology: Acquisitions, Inventor Movement, and Technology Transfer

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by

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## Executive Summary

CHI Research, Inc. has carried out an analysis of the impact of small firms on technological developments. This analysis covers a variety of areas, including the acquisition of small firms, the movement of prolific inventors between organizations, and the dependence of large firms on small firms' technology.

In a previous study, CHI built a database of 1,070 companies with 15 or more patents from 1996-2000, and determined whether each company is a small or large entity. In the present study, that database was extended to include 1,270 companies with 15 or more patents from 1998-2002. Taken together, these two databases are unique, and difficult to reproduce because even small firms tend to patent under multiple names, and some large firms patent under more than 300 names. Having these two databases provides a valuable resource in studying innovation of small and large firms.

The main findings of this report are:

### Company Turnover

- More firms are patenting more often. Of the companies in the 2000 database, 104 companies did not make it into the 2002 database, but 318 companies that were not in the 2000 database are in the 2002 database.

- The technological influence of small firms is increasing. The percentage of highly innovative US firms (those with more than 15 US patents in the last five years) that are defined as small firms increased from 33% in the 2000 database to 40% in the 2002 database.

- The turnover of small firms' presence in the database is higher than that of large firms. Overall, 10% of the firms in the 2000 database were not in the 2002 database, but only 6% of larger firms were dropped, while 14% of small firms were dropped. However, the database volatility is weighted toward entry, and in this respect small firms excel. There are twice as many large firm entrants as large firms drops, but there are four times as many small firm entrants as small firm drops.

- Small companies represent 65% of the new companies in the list of most highly innovative companies in 2002. The industries in which the number of small firms has increased most rapidly are chemicals, pharmaceuticals, biotechnology, medical equipment, office equipment and cameras, and telecommunications.

**Technology Transfer**

- In the aggregate, large firms are citing small firm patents less than expected in their patents. Analyzing all industries together may have obscured the impact of small firms since barriers to entry exclude small firms from a few key industries such as automotive, aerospace and oil research.

- There are many individual industries in which large firms cite a higher than expected number of small firm patents, suggesting they are building extensively on small firms' technology. These industries include hi-tech areas such as biotechnology, medical electronics, semiconductors, and telecommunications. In biotechnology for example, large firms use the technology of small firms at a rate 60% higher than expected. As these industries develop, the dependence of large firms on small firms' technology is likely to increase.

**Inventor Movement**

- The share of highly productive inventors at large firms fell from 72% to 69%, and the share at small firms rose from 12% to 16%, between the mid 1990s and early in the next decade.

- Small firms were particularly attractive destinations for elite inventors previously working for public sector organizations. Inventors working in the public sector were 10% more likely to move to a small firm than we would expect based on an analysis of all inventor movements. Small firms were also attractive destinations for inventors in biotechnology, medical electronics, medical equipment, oil, gas & mining, pharmaceuticals, and textiles.

- Elite inventors at large firms have the greatest tendency to stay with the same company. About three-quarters of large firm inventors stayed with their firm versus about half for small firms and the public sector. Also, elite inventors tend to move within their category, for example from one large firm to another or from one small firm to another small firm.

**Acquisitions**

- One quarter of the 24 acquiring companies gained 50 percent or more of their technology strength (a measure of patents and citations by other patents) through acquisitions.

- Contrary to expectations, large firms do not obtain technology through the acquisition of small firms. A set of 43 firm acquisitions occurring between 1994 and 1998 were examined to determine the extent to which large firms obtain technology through the acquisition of small firms. Surprisingly, there were only a small number of acquisitions of highly innovative small firms by large firms. It was shown that firms gain much of their technological strength through acquisition, but that for the most part this strength is obtained through large company acquisitions and not small company acquisitions.

Overall, analyzing aggregate figures masked small firm technology contributions as shown by their influence in key industries. There are a number of industries with a high turnover of small firms, high dependence of large firms on small firm technology, and extensive inventor movement that are also characterized by a large number of relatively young small firms. These key industries for small firms include biotechnology, medical electronics, medical equipment, and telecommunications.

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## Introduction

In this report, CHI Research, Inc. investigates how small firms expand US innovative capacity, and addresses the question raised by Schumpeter of whether large firms or small firms are more innovative. We frame our analysis in a post-Schumpeterian framework. The sense today is that technology has become dynamic and complex, and networks of innovators have become important as a result. Scholars have noted that small firms add variety to a nation's innovation and that there is an increasing ability to buy and sell technology, which may work to the advantage of small innovators. We thus examine the inter-relationships between small and large innovating firms in order to understand the nature of the unique contribution small firms make to America's innovation. We use three pieces of information to examine such networks:

1. Technology acquisition – large firm acquisition of small firms
2. Technology dependence – large firm dependence on small firm technology
3. Inventor movement – movement of people between large and small firms

We hypothesize that these three indicators of inter-firm technological relations will be correlated with the presence of new, small, technology-intensive firms. Our research will reveal whether technological networking needs to be taken into account in assessing small firms' contribution to innovation and, if so, where such activity is most important.

The issues can be translated into the classic Schumpeterian question. We believe that the small firm contribution to innovation may be understated because large firms buy innovative small firms to acquire their technology, and this technology is often counted as a large firm contribution to innovation. Similarly, when large firms build upon the technology of small firms, the small firm contribution is hidden in many conventional analyses.

We also believe that an exclusive focus on establishing that small firms innovate in the face of barriers obscures important points about the crucial complementary role that small firms play in innovation. For example, people move from large to small firms to pursue ideas outside the primary mission of the large firm. Small firms thus provide a way to maintain variety in a nation's pursuit of technical change. In a new technology, where the best approach is unknown, nations capable of pursuing a greater variety of approaches may well be more successful.

As part of this study, we also updated our data compilation work so that we will have accurate data on small and large firm patenting through 2002. This enables us to conduct our analysis using current data. In addition, we analyze changes between the 2000 and 2002 data and report on the nature of the shifts. We pay particular attention to the percentage of small and large firms that have disappeared and appeared, and the reasons for their disappearance and appearance. This provides a sense of whether growth in innovative output, mergers, acquisitions, and bankruptcies differentially affect small and large innovators.

**Rationale**

For students of the economic role of technical change, the theories of Schumpeter have guided thinking on small firms. In his early work Schumpeter pointed to the important role of innovative entrepreneurs in driving technical change. Many call this Schumpeter Mark I. Later in his career, noting the rise of large industrial R&D laboratories, Schumpeter suggested that the day of the entrepreneur may have passed and that large firms had the advantage in innovation. This thesis is referred to as Schumpeter Mark II.

In the decades since Schumpeter wrote, a theme emerged referencing Schumpeter as a progenitor, regarding whether small or large firms have the advantage in innovation. Small entrepreneurial firms were seen to have an advantage in innovation over large firms because they are highly motivated to innovate, with greater management commitment likely. Small firms also have efficient internal communications, close links with suppliers and customers, and greater speed and flexibility. They also exploit niches that are too specialized for large firms to supply profitably.

On the other hand, small firms lack resources both for large and complex research and for costly development and marketing phases. Their difficulty accessing finance makes it hard to overcome this. They also lack specialist management expertise, and have difficulty coping with government regulation and the patent system. Finally, their smaller markets mean their ability to appropriate returns to innovation is more limited than a large firm. This may suppress their incentive to invest in research and development. (Cohen & Klepper, 1991; Feldman, 1997; Freeman & Soete, 1997; Koen, 1992; Obermeyer, 1981; Romeo 1984; Rubenstein & Ettlie 1984).

Large firms can commit extensive resources to undertake complex research and to carry the results through lengthy development and regulatory approval to launch full-scale marketing campaigns. These advantages are formidable, even more so when combined with their larger market shares over which to appropriate the returns to innovation. Higher returns provide correspondingly greater incentives to pursue research and development. However, large firms can suffer from bureaucratic impediments to the change that innovation implies. This has been known to slow firms down or blind them to the possibilities of innovation, leaving room for small firm entrants (Rothwell & Zegveld, 1982).

There is support here for both the Mark I and Mark II theories. Freeman, in reviewing the subject, reminds us that blanket hypotheses are hard to maintain in this area. Historical studies demonstrated that in synthetic materials, in chemical processes, in nuclear reactors, and in some electronic systems, large firms predominated in launching innovations. In other areas – scientific and medical instruments in particular – small firm contributions stand out (Rappaport, 1990; Shimshoni, 1970).

Cohen and Klepper reviewed the area in 1996 and concluded that, although policy makers believed that large firms had the advantage in innovation, the evidence suggested the opposite for US firms. Studies of R&D expenditure and firm size had indicated that "large firms do not conduct a disproportionate amount of R&D relative to their size, but also indicated that large firms actually generate fewer innovations per dollar of R&D than smaller firms, which has been widely interpreted as reflecting a disadvantage of size" (Cohen & Klepper, 1996, p. 925).

Crucial evidence in this debate was provided by large empirical studies of inventions introduced into the marketplace – i.e. innovations. This work established the efficiency of small firms in producing innovation (SBA, 1986). Acs and Audretsch (1991) compared the studies by Edwards and Gordon (1984), Gellman Research Associates (1982) and Pavitt et al. (1987). These studies analyzed large sets of innovations compiled from trade journals or surveys of experts. Acs and Audretsch point to the similarities in the findings. Gellman found that small firms contributed more than twice as many innovations per employee as did large firms. The Pavitt data pointed to a similar result in recent years. The three studies discovered similar distributions of innovation across industry, with small firm share of innovation being greatest in instruments, followed by non-electrical machinery and electrical equipment. (Acs & Audretsch, 1991, pp. 24-25) Other smaller studies have generally supported the idea that small firms are more efficient at introducing innovations (Edwards & Wallace 1985; Link & Bozeman, 1991; Bomberger 1982 & 1992; Hansen, 1989).

Question marks have been raised over the results of these studies. For example, Pavitt found in his study that the greater efficiency of small firms was a relatively recent phenomenon, and was restricted to the 1980s. Tether (1997,1998) reanalyzed the Pavitt data in the 1990s, and examined the classification of the firms as small or large at the time of the innovation. Tether found that some subsidiaries of large firms had been misclassified as small firms in Pavitt's study. Reclassification of firms by Tether eliminated the statistical significance in Pavitt's finding that small firms were becoming more important to innovation. This points to the need for very high standards of data compilation where analysis of small firms is concerned.

Over time, Schumpeter's thinking changed in response to a shift in the balance in innovation between small and large firms. This change over time is an important aspect of the question. In young industries, small firms probably play a more important role than in mature industries, leading Freeman and Soete to state, "Inventor-entrepreneurs establishing new firms had apparently also been important in the early days of the chemical industry, the automobile industry, the semiconductor and radio industries" (Freeman & Soete, 1997, p. 227). Traditionally, industries consolidated as they evolved, removing small firms as large firms came to predominate.

Audretsch established that in industries in which small firms are more innovative, there are more small firm startups. Audretsch also argued that "new entrants represent, at least in some cases, not merely smaller replicas of the existing incumbent enterprises but also agents of change" (Audretsch, 1995, p. 40). Audretsch attributes high rates of small firm innovation, as might be seen early in an industry's evolution, to the entrepreneurial technological regime in which there is divergence in the expected economic value of a piece of knowledge. In the entrepreneurial regime, this disagreement creates opportunities for small firms and the variety they bring to the pursuit of technical change (Cohen & Klepper, 1991). The entrepreneurial regime contrasts with the routinized technical regime, in which there is less knowledge asymmetry, so research outcomes are less in doubt and large firms can undertake R&D with confidence that there will be a useful outcome to appropriate.

The conclusions to be drawn from the Mark I versus Mark II discussion seem somewhat nuanced. Small firms have advantages in invention and discovery, but many obvious resource-based disadvantages in commercialization (i.e. innovation). Their disadvantages are somewhat counterbalanced by managerial advantages. Empirically, small firm innovators dominate in certain industries and have no presence in others. Small firm presence may be greater in the early stages of an industry, fading as the industry consolidates and innovation becomes routine. Impressive, large-scale studies of commercialized innovation demonstrated that small firms produce technically important innovations quite efficiently compared to large firms, and illustrated the variation across industries.

During the 1990s, the economy evolved in directions usefully framed by this discussion. An entrepreneurial regime emerged in several technologies – biotechnology, new materials, and information and communication technology. New industries with high levels of innovative small firm participation emerged. This we could expect, given our understanding of small firm innovation being greater in the early stages of an industry. Also during the 1990s, management of innovation in large firms improved somewhat, as large firms sought to overcome their bureaucratic inertia and develop some of the flexibility, motivation and other managerial advantages traditional to small firms. At the most extreme point in this development, large firms seemed passé as they lost their best people to the excitement and stock options offered by small, innovative new firms promising high growth.

This raises the question of whether these new industries will start to experience consolidation, as we have seen historically as technologies mature, or whether new industry structures will emerge. Recently, a great deal of attention has been paid to networks of firms in innovation. Freeman proposes:

> *... there is now sufficient evidence on the role of networking in innovation to postulate that the typical pattern of nineteenth-century innovation (the inventor-entrepreneur) and of twentieth-century innovation (the in-house corporate R&D department with good external communications) is now increasingly giving way to a pattern of networking collaborative systems innovation in the twenty-first century. Among the driving forces of this change, two of the most important factors are the increasing complexity of technical change and the systemic nature of many ICT [information and communication technology] innovations. (Freeman & Soete, 1997 p. 225)*

Inter-firm networking in innovation could resolve the tension implicit in the small versus large firm discussion. It might allow a division of labor in which small firms could leverage the advantages of large firm partners in development and marketing to overcome their innovation disadvantages. At the same time, large firms could overcome their disadvantages in invention with small firm partners. Thus, the dynamic complementarities between small and large firm innovation could be realized (Rothwell

& Zegveld, 1982; Laamanen & Autio, 1996). In pharmaceuticals, Gambardella argued that this was becoming possible with changes in the technology of research in biomedicine (Arora & Gambardella, 1994).

The manner in which inter-firm networking relates to small firm innovation is thus an interesting area of study. It is, however, a difficult subject, with a paucity of good theoretical guidance (Rogers et al., 2001). The growth of R&D alliances over the past decade has been established, but this work has been largely empirical (Hagedoorn, 1995). Progress has been made concerning the discovery end of the innovation spectrum with work on the research of biotechnology firms (Powell et al., 1996). However, cooperation is far easier in research, and inter-firm relations are far harder to study in more competitive areas.

In this report, we approach the relationship between small firms and inter-firm networks from the following theoretical perspectives. We take small firms to be concentrations of technological competencies (Autio, 1997) that serve to bring variety to the interacting system of innovating firms. We follow Freeman in postulating that innovating small firms fall into three categories:

Type 1 – New firms that are started to develop or exploit a new invention. Type 1 firms should have low sales and high R&D intensity. They should also be relatively young with relatively short patent histories.

Type 2 – Highly specialized firms with particular expertise, sustained by an intensive research program in a very narrow field. Firms in the instrument industry stand out as classic examples here. Type 2 firms should be relatively old, with long patent histories.

Type 3 – Firms struggling to survive in industries where new product competition makes R&D increasingly necessary. These would be older firms with short patent histories. We believe that these firms could be either large or small and are of less interest here.

We propose to examine three aspects of inter-firm relations:

1) Technology acquisition – small firms are often acquired by larger firms who want access to their technology. This includes not only the intellectual property embodied in the patent portfolio, but also the underlying tacit competencies of the inventors who can develop the technology further. This can be considered a successful outcome for a small firm started to develop an innovative idea. We hypothesize that industries with medium levels of acquisition will show high levels of type 1 firms. Very high levels of acquisition will remove type 1 firms, leaving few independent. On the other hand, very low levels of acquisition may remove a major incentive for inventors to start a firm – an exit strategy with a high payoff.

2) Technology dependence – small firms driving technical change may well provide an important foundation for the technology of large firms who would be loath to build directly on the technology of direct competitors. We hypothesize that industries with many type 1 firms will exhibit relatively higher levels of large firm dependence on small firm technology. On the other hand, we hypothesize that in industries with many type 2 firms, large firm dependence on small firms will be lower. This is because type 2 firms are specialists in small technological niches, so large firms are less likely to build on their technology.

3) Inventor movement - We hypothesize that highly successful inventors move mostly from large to small firms, probably because the large firm could not accommodate their latest ideas. This movement is explicitly a form of variety generation within the innovation system. A large firm may kill a certain idea, but its inventor may believe in it too much to let it die, and so moves or starts a firm to develop the idea. We hypothesize that industries with relatively higher levels of inventor movement will show more type 1 small firms.

In addition, we will examine the two-year turnover rate of companies between 2000 and 2002. If risk and reward are closely related for small innovators, the rate at which small firm innovators disappear due to bankruptcy, acquisition or rapid growth to become large firms should correlate with the rate at which new small innovators appear. We expect industries with high turnover to have many type 1 firms.

We hypothesize that these four phenomena should be correlated. Industries with extensive inventor movement should also exhibit high levels of firm acquisition, high small firm technological dependence and high small firm turnover year-to-year. Further, such industries should have a higher concentration of type 1 small firms.

We hypothesize that type 2 small firms should be found in industries with less inventor movement, less acquisition, less small firm technological dependence and less turnover. Such firms should be concentrated in a few industries, such as instruments, that favor small firm innovators.

## Results

### *Database update / 2-year company turnover rate*

We updated the thesaurus of smaller patenting entities through 2002. We then combined this with CHI's current thesaurus of US companies with 45 or more patents in the previous 5 years. Our identification of company patent portfolios is current, incorporating the latest parent-subsidiary information for even the most complex and fast changing companies.

CHI's first SBA project identified 488 US patenting companies with between 15 and 44 patents in the previous five years. Between 49% and 59% of these were companies with less than 500 employees. In this project we updated our information on these companies and identified 622 independent, non-bankrupt, US firms with 15 to 44 patents in the five years ending in 2002. Building and maintaining these databases is a significant undertaking, because even small companies may file patents under several names, and some large companies have been known to file patents under 300 or more names. For example, Aventis and Invensys file patents under 300 names, and P&G, J&J, General Motors and others file patents under 100+ names.

We used a three-stage process to update the data:

1) We used directories and company websites to check whether the status of each of the 488 companies had changed since 2002. Companies in Chapter 11 bankruptcy were dropped. Companies that had been acquired were incorporated into their new parents. If companies had acquired subsidiaries, or had patented under a variant name, the thesaurus was adjusted.

2) We identified candidate companies not already covered that had 15 or more patents in years 1998-2002 (the previous study covered 1997-2001). Public sector entities were eliminated, along with entities that were clearly foreign.

3) For the candidate companies that remained, we confirmed that each is an independent, non-bankrupt US for-profit firm. If so, we unified the company structure using sources such as the company's website, Who Owns Whom, Mergent, Dun & Bradstreet and Corptech. We determined whether the company is a subsidiary, and if it owns any other companies. As part of this process we updated employee and sales data for companies with less than 1,000 employees. This is to ensure that the designation of small companies remains current. We assumed that companies with 1,000 or more employees did not shrink enough to become small.

Having updated the company database, we examined the two-year turnover rate between the first CHI study and this study. We refer to the first study as Round 1 (R1) and this study as Round 2 (R2). R1 covered firms with at least 15 patents in the 5 years ending 2000. R2 covers firms with at least 15 patents in the 5 years ending 2002. In each study, firms had to be independent, US based, not joint ventures, not bankrupt, for profit entities. We examine how many firms dropped out of the study between R1 and R2, and how many firms are new to the study in R2.

Our analysis is patent-based. A firm is thus counted as new if its patents were not in R1, while a firm is counted as dropped if its patents were in R1, but do not appear in R2. We use this definition to eliminate the effect of mergers, company splits and other restructurings on our figures. Using the patent-based definition, there are several reasons that firms might drop out of R2. Firms that were in R1 might not have at least 15 patents in the five years ending 2002, they might have entered Chapter 11, or a foreign firm might have bought them. Note that if another US firm acquired a Round 1 firm, its patents are in R2 and it is counted as remaining in the study. Similarly, there is more than one reason why firms might be new in round 2. For example, they may be new firms, or pre-existing firms who increased their patent output, either through acquisition or organic growth. This study does not investigate the causes of companies entering or dropping out, but simply counts changes in the company lists between R1 and R2.

Table 1a shows the fate of companies that were in R1. This table reveals that 90% of the firms in Round 1 are also in Round 2. Hence there was a 10% drop out rate. Note that small firms were more than twice as likely to be dropped between R1 and R2 as large firms. Of the small firms in R1, 14% did not make it into R2, largely because they did not have enough patents. The "unknown" firms for which we could find no information had less than a 50% chance of making it into R2. The lack of information about them suggests they were perhaps gone by the time R1 was undertaken and so are no longer producing patents. The "Other" category in the table applies to complicated situations such companies being built from parts of several other companies. In these situations there is again continuity between the patents in R1 and R2, but the ultimate parent company owning the patents changes. Though not reported in the tables, underlying figures reveal that 21 R1 firms have been acquired, almost evenly split between large and small.

Table 1b reveals the origin of companies in R2[1]. This table reports that 25% of the companies in R2 are new to the study. Whereas 13% of the large firms in R2 were not in R1, 40% of the small firms in R2 are new firms. Overall, 65% of the new companies are small firms.

The analysis of turnover between R1 and R2 demonstrates higher volatility among small firms. A higher share of small firms dropped out between R1 and R2, and a higher percentage of small firms in R2 are new entrants. However, between 2000 and 2002, both large and small firm volatility was weighted toward entry. This shows that more firms are patenting more often. This trend was stronger among small firms. There are twice as many large firm entrants as large firm drops, but there are four times as many small firm entrants as small firm drops. Overall, 65% of the new firms are small, while 48% of the dropped firms are small. As a result, the percentage of highly innovative firms that are small rose from 33% in 2000 to 40% in 2002.

This raises the question of whether the number of new small firm entrants varies by industry. To explore this phenomenon we divided the large and small companies into 28 industries. Since identifying the industry of a firm is an inexact and time-consuming process, we inferred an industry for each firm by taking the technology category in which it had the largest number of patents between 1995 and 1999. For example, a company that has the bulk of its patents in aerospace is considered to be an aerospace company.

Table 2 reports the number of firms by industry. The small firm share is also shown for industries with more than 10 firms. Industries in which the small firm share exceeds the expected value (which is the overall share of small firms in the study – 40%) are highlighted in bold. As we found in round 1, small firms form a high proportion of all firms in biotechnology, medical electronics, medical equipment, office equipment & cameras, pharmaceuticals, semiconductors & electronics, and telecommunications.

[1] The numbers of companies in Table 1a and Table 1b differ slightly. This is because our analysis is patent based, and patents must appear or disappear for a company to be counted as added or dropped. As a result, splits, mergers and other restructurings may lead to fewer companies in round 2 without companies being added or dropped.

Table 3 reports the number of new firms by inferred industry. In the few cases with more than 10 new firms, the share of small firms is highlighted if it exceeds the expected value of 65% of all new firms. The list of industries is similar: chemicals, pharmaceuticals, biotechnology, medical equipment, office equipment and cameras, and telecommunications. Referring back to the hypotheses set up at the start of this report, these are the industries in which we would expect to see the highest levels of inventor movement, acquisition of small firms by large firms, and dependence of large firms on small firms' technology.

***Firm Acquisition Analysis***

The purpose of this section of the report is to examine patterns of company acquisition by large firms. To examine this issue, we analyzed the patent portfolios of America's most technologically innovative companies. We examined how many of the patents owned by these companies in 1998 were produced by companies that they owned in 1994, and how many result from acquisitions since 1994.

The firms we examined are all US firms with 45 or more patents in the five years ending 1994, and the five years ending 1998 (these we refer to as "Tech-Line" or "TL" companies below). Only firms existing in both 1994 and 1998 that had sufficient patents in both periods are included. As an example, Lucent is excluded because it did not exist in 1994.

We then looked for patent assignees[2] that were part of a TL company in 1998, but were not part of the company in 1994. Such assignees may show the acquisition of a company by the TL company. In this process, there were two scenarios to which we paid particular attention.

The first scenario involves cases where an assignee changed from one TL company to another between 1994 and 1998, and the original 1994 company was no longer in existence in 1998. The fact that the original assignee disappeared suggests that it may have been acquired (if the original assignee still existed, it is likely that it sold a division to another TL company, and we are less interested in those cases here).

The second scenario occurs where an assignee was not in TL in 1994, but was part of a TL company in 1998. Such assignees may represent acquisitions by the TL company. We eliminated from this list any parents that were not independent companies in 1994 (such as public sector institutions). We also eliminated any assignees whose first patent was issued in 1994 or later, since these are likely to be divisions of the parent that began patenting. Similarly we removed assignees with similar names to the parent company, as they are likely to be divisions that have started patenting since 1994. Those new assignees that remained after this process were classified as US or foreign companies after further research.

[2] The assignee is the organization name given on the front page of a patent. If a company is acquired, its patents will still have the original company as the assignee, unless they have been reassigned by the patent office.

Through the method described above, we identified 43 firms (41 of which were domestic) as being acquired by 24 different parent companies. We researched the 41 domestic firms, and determined that only three of them were small companies at the time of acquisition. Twenty-five were identified as being large companies, and thirteen had no information that could be found to determine size. This identification of company size is a significant undertaking, because of the lack of sales figures and/or employee counts for companies that essentially ceased to exist at the time of acquisition (five to nine years ago).

In the rationale of this report, we proposed to examine whether small companies have a significant effect on the subsequent technological developments of their acquirers. Given that we identified only three such acquisitions of small firms, a significant effect seems unlikely. However, a related question that can be addressed is whether acquisitions in general have a significant effect on the technological strengths of the acquiring companies.

To measure the technological effect of an acquisition, we use a metric known as technological strength. Technological strength is the product of the citation index and the number of patents for the period 1997-99. The citation index is a citation-based measure equal to the number of citations received divided by the expected citations for a patent in the same era and technology class. Technological strength can therefore be regarded as an impact-weighted patent count for a company.

We measured the percentage of a parent company's technological strength that can be attributed to company acquisitions. As an example for a single company, Table 4 shows the relevant statistics for St. Jude Medical Inc. St. Jude acquired four companies between 1994 and 1998, including two small domestic companies (Daig Corp. and Ventritex), one large domestic company (Pacesetter Inc.) and one foreign company (Telectronics N.V.).

Table 4 shows that 92% of its technological strength came from acquisitions, with 72% from the large company acquisition, 18% from the small companies, and 3% from the foreign acquisition. Note also in this case that the acquisitions increased St. Jude's citation index, indicating that the acquisitions had stronger technology than the core company.

For each of the 24 companies involved in an acquisition in 1994-98, Table 5 shows the percentage of technological strength that comes from acquisitions. In six of the 24 cases, 50% or more of the companies' technology strength is due to acquisitions. In a further seven cases, more than 25% of the companies' technology strength is due to acquisitions. Thus the effect of an acquisition on the parent companies is often significant. However, most of the effect is due to large company acquisitions, so it cannot be said that in general small companies provide a significant source of technology strength to larger companies through acquisition. We see from Table 5 that this is true even if we assume the unknown companies are small.

***Technology Dependence***

This section of the report examines whether large firm technology builds upon small firm technology to a greater extent than would be expected, given the number of patents owned by small firms. We examine this issue via citation analysis. We compute the number of citations from the patents issued in 2000 to large firms to the 1995-99 patents of both large and small firms. We then compute the share of citations to the small companies and divide by the expected share, in order to get an index measuring the extent to which large companies build on small company technology.

In 2000, 33,255 patents were issued to large companies. These patents reference a total of 91,144 patents from 1995-99, including 50,919 self-citations, 38,108 citations to large companies, and 2,117 citations to small companies. The question is whether the 2,117 citations to small companies are more or less than expected. The number of citations to small firms is 5.3% of the total (2,117 divided by {38,108 + 2,117}), excluding self-citations. Meanwhile, there are a total of 177,899 patents in the database between 1995 and 1999, including 167,088 (93.9%) from large firms and 10,811 (6.1%) from small firms. Dividing the percentage of citations to small firms (5.3%) by the percentage of patents owned by small firms (6.1%) results in a citation ratio of 0.86. This suggests that large firms build upon the patents of small firms at a rate 14% lower than expected given the number of patents owned by small firms.

This appears to be a disappointing result. However, this finding may be partly caused by the fact that there are many industries where small firms play a marginal role. Analyzing all industries together may therefore obscure the impact of small firms in particular industries.

We therefore placed the companies into the inferred industries described earlier (in the section on company turnover). Table 6 shows the number of small and large firms in each industry, along with the number and share of patents in each industry. Industries where small firms are responsible for at least 10% of the patents are shown in bold. We see that in several industries, such as biotechnology and pharmaceuticals, small firms have a reasonably large share of the patents. In other industries, such as aerospace, and oil and gas exploration, small firms have a very small share of the patents.

We calculated a citation ratio from large to small firms (and small firms to small firms) for each inferred industry. The results are shown in Table 7. Although large firms do not leverage the technology of small firms in general, we see that, in several industries, small firms have a very strong impact. For example, Table 6 shows that small firms make up 41% of the patents in biotechnology. Thus we would expect 41% of the biotechnology citations to go to small firms. In fact, 66% of the citations from large biotechnology company patents go to small firms, and 79% of citations from small biotechnology company patents go to small firms. Referring to Table 7, the citation ratios for small firms are 1.6 and 1.9 respectively for citations from large and small biotechnology firms. This indicates that small biotechnology companies are referenced 60% and 90% more than would be expected for their share of patents. This suggests that much of the biotechnology industry is built upon the technological developments of the small firms in the industry.

Table 7 shows that small firms also have high citation indexes in other industries, including medical electronics, semiconductors, and telecommunications. This suggests that the lack of overall impact discussed above was caused by industries where there are barriers to entry and small firms have little impact. Such industries include the automotive, aerospace and oil industries.

Many of the high-tech industries highlighted in this section also featured prominently in the section on the turnover of small firms. This supports the hypothesis set up in the introduction to this report.

### *Inventor Movement*

Technological interdependence between small and large firms might be manifested in the movement of inventors between firms. When innovators move, they take with them a wealth of tacit knowledge and skills that are difficult to obtain any other way. Thus the firm to which the inventor moves gains technical know-how from the firm losing this inventor.

In our analysis of inventor movements, we concentrated on America's elite innovators. We defined elite innovators as inventors who had a combined total of at least 10 patents in two time periods (1993-95 and 2000-02), and at least one patent in each period. In total, 6,228 inventors qualified as elite inventors using this definition. The importance of this small, elite group of innovators is shown by the fact that they are 1.5% of the 406,641 unique inventors that we identified, but account for 27% of the patents in the two periods.

To analyze the movements of these elite inventors, we examined their first patent in 1993-95 and their final patent in period 2000-02 and compared the assignees. The assignees were unified using CHI's patent assignee to parent company thesaurus. If the inventor's organizational affiliation was the same in both periods, we assumed that the inventor did not move. If the organizations differed, then the inventor was assumed to have moved. Inventor affiliations were classified into six categories – large firm; small firm; public sector; foreign company; unknown (assigned to an organization whose designation could not be determined); and unassigned. Our analysis is based on examining counts of inventors by period, by same/move designation and by affiliation category.

We eliminated from consideration any inventor whose first or last patent was unassigned. This left 5,745 inventors, or 92% of the original set. Out of these inventors, 690 were affiliated with a company whose size is unknown to us, even after further research. These unclassified companies are probably mainly small firms, because we have identified most of the large patenting firms.

The large number of unclassified affiliations is problematic for our analysis. To overcome this difficulty, we include three sets of tables in our analysis. In one set, inventors with unknown affiliations are eliminated, leaving 4,949 inventors. These numbers discriminate against small firms, a higher percentage of which will be in the unclassified group. We therefore also include a second set of tables that include the unknown firms and assume that they are all independent small firms. These tables somewhat overstate the role of small firms because there will be some large firms among the unknown firms. The third set of tables assumes that 75% of the unknown companies are small and 25% are large. We found these percentages typical in our research into the size designation of a sample of the unknown firms. The second and third tables may overstate the extent of inventor movement because the assignees have not been unified. As a result, if an inventor has patents for separate parts of the same company, or the name of the company changes, this will register as an inventor move for unknown companies. These artifacts have been eliminated for classified companies.

The results of the analyses are displayed in Tables 8 through 11.[3] We begin by examining the locations of the elite inventors in 1993-95 and 2000-2002, as shown in Table 8a. This table reveals that 72% of the inventors were at large companies in 1993-95, compared to 12% at small firms. The public sector presence was smaller than that of small companies. There is some evidence to suggest that large firms became less popular and small firms more popular between the first and second time periods. The share of inventors at large firms fell from 72% to 69%, and the share at small firms rose from 12% to 16%, between the mid 1990s and early in the next decade. However, it must be noted that we are examining a set of established and still productive elite inventors. It may be that elite inventors are more likely to develop at large firms and universities but, once established, they prefer to work in small firms. Large firms and the public sector could remain popular breeding grounds for emerging elite inventors. Our analysis does not reflect this, because we are looking at the choices of elite inventors who had become established by the mid 1990s.

This raises the question of which set of inventors shows the greatest propensity to move. Table 8b shows that elite inventors at large firms have the greatest tendency to stay with the same company, followed by those at foreign firms (which are mostly large). Elite inventors in the public sector are the most likely to move, with less than half staying in the same place over the decade examined. Inventors in small firms are somewhat less likely to move than their public sector counterparts, but less than half remained in the same place over the decade.

Tables 9 and 10 address the issue of the preferred destinations of elite inventors. Table 9a shows counts of inventor movements between different types of organization, while Table 9b shows the same data in percentages. Table 10 is derived from these figures, and is designed to show if certain types of organizations are particularly attractive to elite inventors. In this table, multiplying the row and column totals in Table 9, and dividing the result by the total number of inventors, produces the expected values for particular combinations of origin and destination. This expected value is then compared to the

[3] Throughout this discussion, we use the figures based on the assumption that the unclassified companies are 75% small and 25% large.

actual value for a given combination. Ratios greater than one denote favored origin-destination combinations.

Table 10 reveals that elite inventors tend to move within their category, for example from one large firm to another or from one small firm to another small firm. This effect is especially strong for the highly mobile public sector inventors. As for movements across categories, only small firms seem to be an attractive destination, as shown by the ratios greater than one. However, this attraction holds only for public sector or foreign company inventors and not for large firm inventors.

The final question we addressed is whether small firms are a particularly attractive destination to elite inventors working in certain technology areas. We examined the final patent of each inventor in 2000-02. We then counted patents by technology area, and institution type for the inventors who moved. This provided a list, by technology, of inventors who moved, and the type of organization to which they had moved (large firm, small firm etc.) Table 11 reports the results of this analysis. Overall, small firms were a destination for one-quarter of the elite inventors who moved. For inventors working in certain technology areas, however, small firms were a more attractive destination. Technology areas in which more than 25% of the moving elite inventors ended up at small firms were: biotechnology, medical electronics, medical equipment, miscellaneous machinery, miscellaneous manufacturing, oil, gas & mining, other, pharmaceuticals, and textiles.

Some of the industries in this list, notably biotechnology and medical equipment, also had strong small firm activity on other indicators. This supports the hypotheses set up at the start of this report. However, the list also contains other industries, such as textiles and oil and gas, which had lower small firm presence, although the numbers of inventor movements in these industries are relatively small.

**Discussion**

In this analysis we have explored three aspects of technological networking between small and large firms: firm acquisition, technological dependence and inventor movement. We have also examined the two-year turnover among highly innovative firms. We found that firm acquisition activity was at too low a level to provide reliable data by technology, or to provide much evidence of a strong dependence of large firms upon the technology of small firms. However, in the other areas, we found a consistent pattern of a higher level of activity in certain industries such as biotechnology and medical electronics.

Table 12 summarizes the results of this study. This table lists the 30 inferred industries used in this report, along with the results from the three analyses with sufficient data to be robust. Each case in which we found higher than expected results for small firms (for example, both large and small firms over-citing small firm patents) is checked. Industries with two or more checks are highlighted in bold. These industries are biotechnology, medical electronics, medical equipment, pharmaceuticals and telecommunications. These are the industries in which there is a high dependence on small firm technology as evidenced by citations, and/or small firms are particularly attractive destinations for mobile elite inventors, and/or there is a high level of turnover among small firms.

We hypothesized that in these industries, we would see a lot of type 1 small firms (i.e. new firms started to develop or exploit a new invention). We crudely operationalized type 1 firms as young firms, and used year of first patent application as a proxy for the age of the firm. The percentage of young firms (i.e. firms whose first patent was after 1990) in each industry is shown in Table 13. Industries in which there are a high percentage of young firms are also checked in Table 12. This table shows that there is a great deal of agreement between the presence of type 1 firms, and industries in which small firms have a high impact according to our other indicators, confirming our original hypothesis. In particular, biotechnology, medical electronics, medical equipment, and telecommunications have a high presence of type 1 firms. From our indicators, we would expect, but do not see, a high small firm presence in pharmaceuticals. Conversely, there are a large number of young small firms in semiconductors, an industry that does not figure prominently on the other indicators.

## Conclusions

In conclusion, the late 1990s into 2000 was a very good time for highly innovative small firms. They increased their presence among the nation's most innovative firms from 33% to 40% during this period. In addition, we have found that in certain key technology areas/industries:

- small firms are an attractive destination for elite inventors
- large and small firms rely heavily on small firm technology
- we see increasing numbers of highly innovative small firms

In these industries, we tend to find a high percentage of the small firms being younger firms, suggesting that many of them may have been started to develop or exploit a new invention. The key industries for innovative small firms are: biotechnology, medical electronics, medical equipment, and telecommunications.

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### Table 1a - Fate of Companies in Round 1

| | Large | Small | Unknown | Total |
|---|---|---|---|---|
| In round 2 | 638 (93%) | 307 (86%) | 13 (48%) | 958 (90%) |
| Dropped | 42 (6%) | 48 (14%) | 14 (52%) | 104 (10%) |
| Other | 8 (1%) | | | 8 (1%) |
| Total | 688 (100%) | 355 (100%) | 27 (100%) | 1070 (100%) |

### Table 1b – Origin of companies in Round 2

| | Large | Small | Unknown | Total |
|---|---|---|---|---|
| In round 1 | 629 (85%) | 304 (60%) | 8 (57%) | 941 (74%) |
| New | 99 (13%) | 212 (40%) | 7 (43%) | 318 (25%) |
| Other | 11 (2%) | | | 11 (1%) |
| Total | 739 | 516 | 15 | 1270 |

## Table 2 - Number of firms by inferred industry

**Industries with small firm share greater than 40% shown in bold**

| Inferred Industry | Share small | Large | Small | Unknown | Total |
|---|---|---|---|---|---|
| Aerospace & Parts | | 1 | | | 1 |
| Agriculture | 32% | 15 | 7 | | 22 |
| Biotechnology | **74%** | 14 | 39 | | 53 |
| Chemicals | 40% | 68 | 45 | | 113 |
| Computers & Peripherals | 37% | 79 | 46 | 1 | 126 |
| Electrical Appliances & Components | 31% | 47 | 22 | 2 | 71 |
| Fabricated Metals | | 4 | 3 | | 7 |
| Food & Tobacco | 22% | 14 | 4 | | 18 |
| Glass, Clay & Cement | | | 1 | | 1 |
| Heating, Ventilation, Refrigeration | | 3 | 4 | 1 | 8 |
| Industrial Machinery & Tools | 27% | 43 | 16 | | 59 |
| Industrial Process Equipment | 33% | 25 | 13 | 1 | 39 |
| Measurement & Control Equipment | 34% | 23 | 13 | 2 | 38 |
| Medical Electronics | **72%** | 3 | 13 | 2 | 18 |
| Medical Equipment | **59%** | 41 | 61 | 2 | 104 |
| Misc. Machinery | 27% | 43 | 16 | | 59 |
| Misc. Manufacturing | 26% | 56 | 20 | 2 | 78 |
| Motor Vehicles & Parts | 17% | 30 | 6 | | 36 |
| Office Equipment & Cameras | **48%** | 24 | 22 | | 46 |
| Oil & Gas, Mining | 16% | 16 | 3 | | 19 |
| Other | 33% | 19 | 10 | 1 | 30 |
| Other Transport | 18% | 9 | 2 | | 11 |
| Pharmaceuticals | **69%** | 20 | 45 | | 65 |
| Plastics, Polymers & Rubber | 35% | 17 | 9 | | 26 |
| Power Generation & Distribution | | 1 | 5 | | 6 |
| Primary Metals | | 7 | 1 | | 8 |
| Semiconductors & Electronics | **48%** | 27 | 25 | | 52 |
| Telecommunications | **47%** | 62 | 56 | 1 | 119 |
| Textiles & Apparel | 27% | 11 | 4 | | 15 |
| Wood & Paper | 23% | 17 | 5 | | 22 |
| Total | 41% | 739 | 516 | 15 | 1,270 |

## Table 3 - New firms by inferred industry

### Industries with more than 10 new firms where more than 65% of new firms are small are shown in bold

| Inferred Industry | Share small | Large | Small | Unknown | Total |
|---|---|---|---|---|---|
| Aerospace & Parts | | | | | 0 |
| Agriculture | 20% | 4 | 1 | | 5 |
| Biotechnology | **82%** | 3 | 14 | | 17 |
| Chemicals | **71%** | 8 | 20 | | 28 |
| Computers & Peripherals | 58% | 14 | 21 | 1 | 36 |
| Electrical Appliances & Components | 52% | 8 | 11 | 2 | 21 |
| Fabricated Metals | 100% | | 3 | | 3 |
| Food & Tobacco | 33% | 2 | 1 | | 3 |
| Glass, Clay & Cement | | | | | 0 |
| Heating, Ventilation, Refrigeration | | | | 1 | 1 |
| Industrial Machinery & Tools | 58% | 5 | 7 | | 12 |
| Industrial Process Equipment | 67% | 2 | 4 | | 6 |
| Measurement & Control Equipment | 71% | 2 | 5 | | 7 |
| Medical Electronics | 80% | | 4 | 1 | 5 |
| Medical Equipment | **94%** | 2 | 29 | | 31 |
| Misc. Machinery | 60% | 6 | 9 | | 15 |
| Misc. Manufacturing | 55% | 8 | 11 | 1 | 20 |
| Motor Vehicles & Parts | 100% | | 2 | | 2 |
| Office Equipment & Cameras | **71%** | 4 | 10 | | 14 |
| Oil & Gas, Mining | 67% | 1 | 2 | | 3 |
| Other | 29% | 4 | 2 | 1 | 7 |
| Other Transport | 33% | 2 | 1 | | 3 |
| Pharmaceuticals | **86%** | 2 | 12 | | 14 |
| Plastics, Polymers & Rubber | 71% | 2 | 5 | | 7 |
| Power Generation & Distribution | 100% | | 1 | | 1 |
| Primary Metals | 100% | | 1 | | 1 |
| Semiconductors & Electronics | 62% | 5 | 8 | | 13 |
| Telecommunications | **71%** | 10 | 24 | | 34 |
| Textiles & Apparel | 40% | 3 | 2 | | 5 |
| Wood & Paper | 50% | 2 | 2 | | 4 |
| Total | 67% | 99 | 212 | 7 | 318 |

**Table 4**
**St. Jude Medical Inc. 1997-99 Patent Metrics**

| Source | # Patents | Citation Index | Technology Strength | % of Strength |
|---|---|---|---|---|
| Core Company | 35 | 0.58 | 20 | 8% |
| Large Company Acquisitions | 241 | 0.8 | 194 | 72% |
| Foreign Company Acquisitions | 3 | 2.52 | 8 | 3% |
| Small Company Acquisitions | 47 | 1.03 | 48 | 18% |
| Unknown Size Acquisitions | 0 | 0 | 0 | 0% |
| Totals | 326 | 0.83 | 270 | 100% |

Citation Index is a measure of how frequently a company's patents are cited by subsequent patents
Technology Strength is calculated by multiplying a company's number of patents by its citation index
% of Strength shows the percentage of a company's Technology Strength accounted for by each acquisition

**Table 5 - Percentage of Companies' Technology Strength by Type of Acquisition**

| Parent Name | *total - core* | *large* | *core* | *foreign* | *small* | *unknown* |
|---|---|---|---|---|---|---|
| St. Jude Medical Inc. | 92% | 72% | 8% | 3% | 18% | 0% |
| Science Applications Int'l | 90% | 90% | 10% | 0% | 0% | 0% |
| Guidant Corp | 83% | 57% | 17% | 0% | 0% | 26% |
| Crompton & Knowles Corp | 81% | 81% | 19% | 0% | 0% | 0% |
| Johnson Controls Inc. | 70% | 70% | 30% | 0% | 0% | 0% |
| Sofamor Danek Group | 50% | 50% | 50% | 0% | 0% | 0% |
| Compaq Computer Corp. | 42% | 42% | 58% | 0% | 0% | 0% |
| Raytheon Company | 40% | 40% | 60% | 0% | 0% | 0% |
| Boeing Co, The | 40% | 40% | 60% | 0% | 0% | 0% |
| Baker Hughes Inc | 37% | 37% | 63% | 0% | 0% | 0% |
| Dover Corporation | 30% | 0% | 70% | 0% | 30% | 0% |
| Boston Scientific Corp | 29% | 29% | 71% | 0% | 0% | 0% |
| Gillette Co The | 26% | 26% | 74% | 0% | 0% | 0% |
| Mark IV Industries Inc | 23% | 21% | 77% | 0% | 0% | 2% |
| Beckman Coulter Inc | 23% | 23% | 77% | 0% | 0% | 0% |
| Rockwell International | 20% | 0% | 80% | 0% | 0% | 20% |
| Johnson & Johnson | 20% | 20% | 80% | 0% | 0% | 0% |
| Thomas & Betts Corp | 17% | 17% | 83% | 0% | 0% | 0% |
| Silicon Graphics Inc. | 13% | 13% | 87% | 0% | 0% | 0% |
| Mallinckrodt Group, Inc. | 13% | 13% | 87% | 0% | 0% | 0% |
| Baxter International Inc | 11% | 0% | 89% | 11% | 0% | 0% |
| Cirrus Logic Inc. | 9% | 0% | 91% | 0% | 0% | 9% |
| Dow Chemical Co | 9% | 9% | 91% | 0% | 0% | 0% |
| E I DuPont de Nemours | 4% | 4% | 96% | 0% | 0% | 0% |

Table 6 -- Number of Small and Large Firms by Industry
(Industries inferred based on largest patent category 1995-99)

| | # Firms | | | # 1995-99 Patents | | | % Patents | |
|---|---|---|---|---|---|---|---|---|
| **Inferred Industry** | **Large** | **Small** | **Total** | **Large** | **Small** | **Total** | **Large** | **Small** |
| Aerospace & Parts | 3 | 1 | 4 | 1,126 | 13 | 1,139 | 99% | 1% |
| Agriculture | 15 | 7 | 22 | 1,485 | 161 | 1,646 | 90% | **10%** |
| Biotechnology | 19 | 39 | 58 | 1,563 | 1,090 | 2,653 | 59% | **41%** |
| Chemicals | 66 | 46 | 112 | 12,514 | 1,047 | 13,561 | 92% | 8% |
| Computers & Peripherals | 79 | 46 | 125 | 31,686 | 923 | 32,609 | 97% | 3% |
| Electrical Appliances & Components | 47 | 22 | 69 | 8,397 | 479 | 8,876 | 95% | 5% |
| Fabricated Metals | 7 | 5 | 12 | 1,390 | 142 | 1,532 | 91% | 9% |
| Food & Tobacco | 13 | 3 | 16 | 1,042 | 60 | 1,102 | 95% | 5% |
| Heating, Ventilation, Refrigeration | 6 | 3 | 9 | 468 | 53 | 521 | 90% | **10%** |
| Industrial Machinery & Tools | 40 | 18 | 58 | 3,596 | 226 | 3,822 | 94% | 6% |
| Industrial Process Equipment | 24 | 11 | 35 | 1,863 | 243 | 2,106 | 88% | **12%** |
| Measurement & Control Equipment | 21 | 14 | 35 | 6,827 | 216 | 7,043 | 97% | 3% |
| Medical Electronics | 6 | 14 | 20 | 748 | 263 | 1,011 | 74% | **26%** |
| Medical Equipment | 41 | 54 | 95 | 9,302 | 952 | 10,254 | 91% | 9% |
| Misc. Machinery | 46 | 18 | 64 | 5,638 | 228 | 5,866 | 96% | 4% |
| Misc. Manufacturing | 64 | 22 | 86 | 7,248 | 389 | 7,637 | 95% | 5% |
| Motor Vehicles & Parts | 30 | 6 | 36 | 9,613 | 206 | 9,819 | 98% | 2% |
| Office Equipment & Cameras | 23 | 21 | 44 | 10,269 | 342 | 10,611 | 97% | 3% |
| Oil & Gas, Mining | 16 | 2 | 18 | 4,557 | 25 | 4,582 | 99% | 1% |
| Other Transport | 8 | 3 | 11 | 485 | 34 | 519 | 93% | 7% |
| Pharmaceuticals | 18 | 50 | 68 | 7,030 | 1,603 | 8,633 | 81% | **19%** |
| Plastics, Polymers & Rubber | 23 | 10 | 33 | 8,423 | 152 | 8,575 | 98% | 2% |
| Primary Metals | 6 | 0 | 6 | 298 | 0 | 298 | 100% | 0% |
| Semiconductors & Electronics | 26 | 24 | 50 | 9,284 | 541 | 9,825 | 94% | 6% |
| Telecommunications | 69 | 50 | 119 | 19,642 | 889 | 20,531 | 96% | 4% |
| Textiles & Apparel | 11 | 4 | 15 | 540 | 54 | 594 | 91% | 9% |
| Wood & Paper | 14 | 5 | 19 | 1,125 | 86 | 1,211 | 93% | 7% |
| Other | 21 | 16 | 37 | 929 | 394 | 1,323 | 70% | **30%** |
| All Patents | 762 | 514 | 1,276 | 167,088 | 10,811 | 177,899 | 94% | 6% |

**Inustries where at least 10% of patents are from small firms are shown in bold**

## Table 7
## Industries Where Small Firms Have the Highest Citation Impact
## (2002 Patents Citing to 1995-99 Patents)

| | Source Companies | | | Citation Index | |
|---|---|---|---|---|---|
| **Inferred Industry** | **Size** | **# Firms** | **# Patents** | **to Large Firms** | **to Small Firms** |
| Agriculture | Large | 15 | 1,485 | 0.7 | **4.1** |
| | Small | 7 | 161 | 1.1 | 0.0 |
| | Total | 22 | 1,646 | 0.7 | **3.7** |
| Chemicals | Large | 66 | 12,514 | 1.0 | 1.0 |
| | Small | 46 | 1,047 | 0.8 | **3.2** |
| | Total | 112 | 13,561 | 1.0 | **1.5** |
| Biotechnology | Large | 19 | 1,563 | 0.6 | **1.6** |
| | Small | 39 | 1,090 | 0.4 | **1.9** |
| | Total | 58 | 2,653 | 0.4 | **1.8** |
| Medical Equipment | Large | 41 | 9,302 | 1.0 | 0.9 |
| | Small | 54 | 952 | 0.9 | **1.5** |
| | Total | 95 | 10,254 | 1.0 | 1.0 |
| Medical Electronics | Large | 6 | 748 | 0.0 | **3.8** |
| | Small | 14 | 263 | 0.8 | **1.6** |
| | Total | 20 | 1,011 | 0.4 | **2.7** |
| Plastics, Polymers & Rubber | Large | 23 | 8,423 | 1.0 | **2.3** |
| | Small | 10 | 152 | 1.0 | 1.3 |
| | Total | 33 | 8,575 | 1.0 | **2.0** |
| Fabricated Metals | Large | 7 | 1,390 | 0.7 | **3.9** |
| | Small | 5 | 142 | 1.1 | 0.0 |
| | Total | 12 | 1,532 | 0.8 | **3.1** |
| Industrial Machinery & Tools | Large | 40 | 3,596 | 1.0 | 0.9 |
| | Small | 18 | 226 | 0.9 | **2.0** |
| | Total | 58 | 3,822 | 1.0 | 1.1 |
| Office Equipment & Cameras | Large | 23 | 10,269 | 1.0 | **2.0** |
| | Small | 21 | 342 | 1.0 | 0.4 |
| | Total | 44 | 10,611 | 1.0 | **1.6** |
| Misc. Machinery | Large | 46 | 5,638 | 1.0 | **2.0** |
| | Small | 18 | 228 | 1.0 | 0.0 |
| | Total | 64 | 5,866 | 1.0 | **1.9** |
| Telecommunications | Large | 69 | 19,642 | 1.0 | 1.1 |
| | Small | 50 | 889 | 1.0 | **1.6** |
| | Total | 119 | 20,531 | 1.0 | 1.2 |
| Semiconductors & Electronics | Large | 26 | 9,284 | 1.0 | **1.8** |
| | Small | 24 | 541 | 0.9 | **3.1** |
| | Total | 50 | 9,825 | 1.0 | **1.8** |
| Measurement & Control Equipment | Large | 21 | 6,827 | 1.0 | **1.9** |
| | Small | 14 | 216 | 1.0 | **1.9** |
| | Total | 35 | 7,043 | 1.0 | **1.9** |
| All Patents | Large | 762 | 167,088 | 1.0 | 0.9 |
| | Small | 514 | 10,811 | 0.9 | **2.9** |
| | Total | 1,276 | 177,899 | 1.0 | 1.1 |

**Citation Index is a measure of how frequently a company's patents are cited by subsequent patents**
**Industries with Citation Index values over 1.0 are shown in bold**

## Table 8a - Period 1 and period 2 elite inventor shares compared

Assume unclassified firms 75% small/25% large

| Category | 1993-95 | 2000-02 |
|---|---|---|
| Large firms | 4,119 (72%) | 3,970 (69%) |
| Small firms | 685 (12%) | 932 (16%) |
| Public Sector | 415 (7%) | 299 (5%) |
| Foreign firms | 524 (9%) | 542 (9%) |
| Total | 5,743 (100%) | 5,743 (100%) |

Including only firms in known categories

| Category | 1993-95 | 2000-02 |
|---|---|---|
| Large firms | 3,819 (76%) | 3,715 (74%) |
| Small firms | 377 (7%) | 529 (10%) |
| Public Sector | 369 (7%) | 285 (6%) |
| Foreign firms | 477 (9%) | 513 (10%) |
| Total | 5,042 (100%) | 5,042 (100%) |

Assuming unclassified firms are small

| Category | 1993-95 | 2000-02 |
|---|---|---|
| Large firms | 4,021 (70%) | 3,852 (67%) |
| Small firms | 783 (14%) | 1,052 (18%) |
| Public Sector | 417 (7%) | 299 (5%) |
| Foreign firms | 524 (9%) | 542 (9%) |
| Total | 5,745 (100%) | 5,745 (100%) |

## Table 8b - How many elite inventors stay and how many move?

Assume unclassified firms 75% small/25% large

| Category | Same | Move |
|---|---|---|
| Large firms | 2,827 (69%) | 1,292 (31%) |
| Small firms | 334 (49%) | 351 (51%) |
| Public Sector | 181 (44%) | 234 (56%) |
| Foreign firms | 284 (54%) | 240 (46%) |
| Total | 3,625 (63%) | 2,118 (37%) |

Including only firms in known categories

| Category | Same | Move |
|---|---|---|
| Large firms | 2,815 (74%) | 1,004 (26%) |
| Small firms | 299 (79%) | 78 (21%) |
| Public Sector | 181 (49%) | 188 (51%) |
| Foreign firms | 284 (60%) | 193 (40%) |
| Total | 3,579 (71%) | 1,463 (29%) |

Assuming unclassified firms are small

| Category | Same | Move |
|---|---|---|
| Large firms | 2,815 (70%) | 1,206 (30%) |
| Small firms | 345 (44%) | 438 (56%) |
| Public Sector | 181 (43%) | 236 (57%) |
| Foreign firms | 284 (54%) | 240 (46%) |
| Total | 3,625 (63%) | 2,120 (37%) |

## Table 9a - Counts of Inventor Movements

**Assuming unclassified firms are 75% small/25% large**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 2,827 | 1,292 | 769 | 318 | 63 | 142 |
| Small firms | 334 | 352 | 169 | 131 | 17 | 35 |
| Public Sector | 181 | 234 | 106 | 73 | 32 | 23 |
| Foreign firms | 284 | 240 | 99 | 76 | 7 | 58 |
| Total | 3,625 | 2,118 | 1,144 | 599 | 118 | 258 |

**Including only firms in known categories**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 2,815 | 1,004 | 677 | 133 | 59 | 135 |
| Small firms | 299 | 78 | 40 | 19 | 6 | 13 |
| Public Sector | 181 | 188 | 96 | 37 | 32 | 23 |
| Foreign firms | 284 | 193 | 87 | 41 | 7 | 58 |
| Total | 3,579 | 1,463 | 900 | 230 | 104 | 229 |

**Assuming unclassified firms are independent small firms**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 2,815 | 1,206 | 677 | 335 | 59 | 135 |
| Small firms | 345 | 438 | 177 | 199 | 20 | 42 |
| Public Sector | 181 | 236 | 96 | 85 | 32 | 23 |
| Foreign firms | 284 | 240 | 87 | 88 | 7 | 58 |
| Total | 3,625 | 2,120 | 1,037 | 707 | 118 | 258 |

## Table 9b - Percentages of Inventor Movements

**Assuming unclassified firms are 75% small/25% large**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 78% | 61% | 36% | 15% | 3% | 7% |
| Small firms | 9% | 17% | 8% | 6% | 1% | 2% |
| Public Sector | 5% | 11% | 5% | 3% | 2% | 1% |
| Foreign firms | 8% | 11% | 5% | 4% | 0% | 3% |
| Total | 100% | 100% | | | | |

**Including only firms in known categories**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 79% | 69% | 46% | 9% | 4% | 9% |
| Small firms | 8% | 5% | 3% | 1% | 0% | 1% |
| Public Sector | 5% | 13% | 7% | 3% | 2% | 2% |
| Foreign firms | 8% | 13% | 6% | 3% | 0% | 4% |
| Total | 100% | 100% | | | | |

**Assuming unclassified firms are independent small firms**

| | | | Moving to | | | |
|---|---|---|---|---|---|---|
| **Moving from** | Same | Move | Large firms | Small firms | Public Sector | Foreign firms |
| Large firms | 78% | 57% | 32% | 16% | 3% | 6% |
| Small firms | 10% | 21% | 8% | 9% | 1% | 2% |
| Public Sector | 5% | 11% | 5% | 4% | 2% | 1% |
| Foreign firms | 8% | 11% | 4% | 4% | 0% | 3% |
| Total | 100% | 100% | | | | |

## Table 10 - Actual/expected ratio for inventor movements

Expected value = row total * column total / all movers

Assume unclassified firms 75% small/25% large

| | Moving to: | | | |
|---|---|---|---|---|
| | Large firms | Small firms | Public Sector | Foreign firms |
| **Moving from:** | | | | |
| Large firms | 1.10 | 0.87 | 0.87 | 0.90 |
| Small firms | 0.89 | 1.32 | 0.84 | 0.81 |
| Public Sector | 0.84 | 1.10 | 2.45 | 0.81 |
| Foreign firms | 0.76 | 1.12 | 0.52 | 1.98 |

Including only firms in known categories

| | Moving to: | | | |
|---|---|---|---|---|
| | Large firms | Small firms | Public Sector | Foreign firms |
| **Moving from:** | | | | |
| Large firms | 1.1 | 0.8 | 0.8 | 0.9 |
| Small firms | 0.8 | 1.5 | 1.1 | 1.1 |
| Public Sector | 0.8 | 1.3 | 2.4 | 0.8 |
| Foreign firms | 0.7 | 1.4 | 0.5 | 1.9 |

Assuming unclassified firms are small

| | Moving to: | | | |
|---|---|---|---|---|
| Category | Large firms | Small firms | Public Sector | Foreign firms |
| **Moving from:** | | | | |
| Large firms | 1.1 | 0.8 | 0.9 | 0.9 |
| Small firms | 0.8 | 1.4 | 0.8 | 0.8 |
| Public Sector | 0.8 | 1.1 | 2.4 | 0.8 |
| Foreign firms | 0.7 | 1.1 | 0.5 | 2.0 |

**Values greater than 1 show more inventor movements than expected**

## Table 11 - Small firm share of elite inventor destinations by technology area

**Assuming unclassified firms split into 75% small and 25% large**

**Industries where over 25% of destinations are small firms are shown in bold**

| Technology area | Small firm share | Large firm | Small firm | Public Sector | Foreign firm | Total Moves |
|---|---|---|---|---|---|---|
| Aerospace & Parts | | 3 | 2 | | | 5 |
| Agriculture | 24% | 15 | 9 | 4 | 10 | 38 |
| Biotechnology | **31%** | 13 | 11 | 9 | 3 | 36 |
| Chemicals | 22% | 125 | 50 | 17 | 38 | 230 |
| Computers & Peripherals | 21% | 113 | 40 | 5 | 29 | 186 |
| Electrical Appliances & Components | 20% | 49 | 18 | 6 | 17 | 89 |
| Fabricated Metals | | 16 | 1 | 1 | 1 | 19 |
| Food & Tobacco | | 6 | 2 | | 2 | 9 |
| Glass, Clay & Cement | | 4 | 2 | | 1 | 7 |
| Heating, Ventilation, Refrigeration | | 6 | 5 | | | 10 |
| Industrial Machinery & Tools | 21% | 33 | 10 | 2 | 4 | 49 |
| Industrial Process Equipment | 25% | 22 | 11 | 3 | 7 | 42 |
| Measurement & Control Equipment | 25% | 35 | 19 | 14 | 8 | 76 |
| Medical Electronics | **33%** | 27 | 19 | 4 | 8 | 58 |
| Medical Equipment | **42%** | 71 | 58 | 4 | 4 | 137 |
| Misc. Machinery | **30%** | 20 | 11 | 1 | 5 | 37 |
| Misc. Manufacturing | **38%** | 26 | 22 | 3 | 8 | 59 |
| Motor Vehicles & Parts | 16% | 30 | 7 | | 5 | 42 |
| Office Equipment & Cameras | 23% | 90 | 32 | 4 | 13 | 138 |
| Oil & Gas, Mining | **28%** | 10 | 6 | | 5 | 20 |
| Other | **46%** | 16 | 16 | 2 | 1 | 35 |
| Other Transport | | 6 | 3 | 1 | 1 | 10 |
| Pharmaceuticals | **31%** | 59 | 41 | 9 | 22 | 131 |
| Plastics, Polymers & Rubber | 18% | 48 | 17 | 10 | 21 | 96 |
| Power Generation & Distribution | 24% | 12 | 4 | 1 | 1 | 18 |
| Primary Metals | | 5 | 4 | 1 | 2 | 11 |
| Semiconductors & Electronics | 17% | 138 | 34 | 10 | 18 | 200 |
| Telecommunications | 21% | 97 | 32 | 4 | 15 | 148 |
| Textiles & Apparel | **34%** | 10 | 8 | 3 | 2 | 22 |
| Wood & Paper | 21% | 9 | 4 | | 7 | 20 |
| Total | 25% | 1,108 | 495 | 118 | 258 | 1,978 |

## Table 12 - Industries with high levels of small firm activity

**Check mark represents higher than average small firm activity in particular area**

**Industries with more than two check marks are shown in bold**

| Technology area | Citation dependence | Inventor movement | 2-year turnover | High Share of Small Firms are Young |
|---|---|---|---|---|
| Agriculture | | | | |
| **Biotechnology** | ✓ | ✓ | ✓ | ✓ |
| Chemicals | | | ✓ | |
| Computers & Peripherals | | | | ✓ |
| Electrical Appliances & Components | | | | |
| Fabricated Metals | | | | |
| Food & Tobacco | | | | |
| Glass, Clay & Cement | | | | |
| Heating, Ventilation, Refrigeration | | | | |
| Industrial Machinery & Tools | | | | |
| Industrial Process Equipment | | | | |
| Measurement & Control Equipment | ✓ | | | |
| **Medical Electronics** | ✓ | ✓ | | ✓ |
| **Medical Equipment** | | ✓ | ✓ | ✓ |
| Misc. Machinery | | ✓ | | |
| Misc. Manufacturing | | ✓ | | |
| Motor Vehicles & Parts | | | | |
| Office Equipment & Cameras | | | ✓ | |
| Oil & Gas, Mining | | ✓ | | |
| Other | | ✓ | | |
| Other Transport | | | | |
| **Pharmaceuticals** | | ✓ | ✓ | |
| Plastics, Polymers & Rubber | | | | |
| Power Generation & Distribution | | | | |
| Primary Metals | | | | |
| Semiconductors & Electronics | ✓ | | | ✓ |
| **Telecommunications** | ✓ | | ✓ | ✓ |
| Textiles & Apparel | | ✓ | | |
| Wood & Paper | | | | |

## Table 13 - Percentage of small firms that are young by technology area

Young firms are defined as having first patent after 1989

Industries where young firms account for more than 49% of total firms are shown in bold

| Technology area | Share small firms 1990 or later | First Patent Pre-1990 | First Patent 1990 or later | All |
|---|---|---|---|---|
| Agriculture | | 4 | 3 | 7 |
| Biotechnology | **69%** | 12 | 27 | 39 |
| Chemicals | 38% | 28 | 17 | 45 |
| Computers & Peripherals | **67%** | 15 | 31 | 46 |
| Electrical Appliances & Components | 32% | 15 | 7 | 22 |
| Fabricated Metals | | 3 | 0 | 3 |
| Food & Tobacco | | 3 | 1 | 4 |
| Glass, Clay & Cement | | 1 | 0 | 1 |
| Heating, Ventilation, Refrigeration | | 4 | 0 | 4 |
| Industrial Machinery & Tools | 31% | 11 | 5 | 16 |
| Industrial Process Equipment | 46% | 7 | 6 | 13 |
| Measurement & Control Equipment | 31% | 9 | 4 | 13 |
| Medical Electronics | **69%** | 4 | 9 | 13 |
| Medical Equipment | **57%** | 26 | 35 | 61 |
| Misc. Machinery | 31% | 11 | 5 | 16 |
| Misc. Manufacturing | 25% | 15 | 5 | 20 |
| Motor Vehicles & Parts | | 5 | 1 | 6 |
| Office Equipment & Cameras | 45% | 12 | 10 | 22 |
| Oil & Gas, Mining | | 1 | 2 | 3 |
| Other | | 8 | 2 | 10 |
| Other Transport | | 1 | 1 | 2 |
| Pharmaceuticals | 49% | 23 | 22 | 45 |
| Plastics, Polymers & Rubber | | 4 | 5 | 9 |
| Power Generation & Distribution | | 2 | 3 | 5 |
| Primary Metals | | 0 | 1 | 1 |
| Semiconductors & Electronics | **64%** | 9 | 16 | 25 |
| Telecommunications | **59%** | 23 | 33 | 56 |
| Textiles & Apparel | | 2 | 2 | 4 |
| Wood & Paper | | 4 | 1 | 5 |
| Total | 49% | 262 | 254 | 516 |

## Appendix A – Detailed methodology for inventor movement analysis

**Selection of base set of patents:** We identified 432,430 US-invented utility patents[4], granted in the two time periods: period 1 (1993-1995) and period 2 (2000 – 2002). By US-invented we mean that there was at least one inventor on the patent with a US address of residence.

**Inventor name unification:** Prior to determining the most prolific inventors, we unified the 916,918 US-resident inventor names on the 432,430 US patents. The purpose was, as best as we could, to give each inventor credit for all his/her patents, including cases where name variants occurred. These variants include where the middle name is spelled in full in some patents, but only the middle initial is given in others; double versus single letter spelling errors; and transpositions of the letters in a name. After unification, we identified 6,228 "prolific" inventors who have at least 10 patents in 1993-95 and 2000-02 combined, and at least one patent in both of these periods. The most prolific of these inventors is Donald E. Weder, Highland, Illinois, with 350 patents. The second most prolific is Mark I. Gardner, Cedar Creek, Texas, with 271 patents.

An inventor may have changed organizations more than once. We make the assumption here that the each inventor's organizational change from period 1 to period 2 is determined based solely on the patent assignments on his/her earliest period 1 patent and latest period 2 patent, where earliest and latest patents are determined by the patent application date.

Weder's earliest patent is assigned to Southland Supply Corp and his last is assigned to Southpac Trust International Inc. Gardner's oldest and newest patents are both assigned to Advanced Micro Devices. So, in Weder's case we say he changed organizations, while Gardner stayed with the same organization.

**Organizational unification:** Using both CHI's Tech-Line® database and the SBA name-to-ultimate parent company name unification tables, we mapped the first-given assignee name on each inventor's earliest period 1 and most recent period 2 patents to their ultimate parent names. If the period 1 and period 2 ultimate parent names were the same, then we determined that the inventor stayed in the same organization from period 1 to period 2. Co-assigned patents were checked separately and corrections made where use of a first assignee created a false move.

We then classified each organization by type. Public sector organizations include government departments and agencies, research institutes, universities and colleges, and hospitals. Non-public-sector organizations were tagged as foreign based on a number of criteria. The one most used was the ultimate parent home address in the Tech-Line database. A US-based subsidiary of a foreign corporation was tagged as foreign. We also made manual adjustments to the data where we recognized a foreign parent company, for example, a German public company name.

[4] A utility patent "may be granted to anyone who invents or discovers any new, useful, and nonobvious process, machine, article of manufacture, or composition of matter, or any new and useful improvement thereof." [source: www.uspto.gov - glossary]

US firms were coded as large or small depending on whether they employed more or less than 500 people. All available sources were checked to determine size – the Internet, Mergent, Corptech, Hoovers, Media General, Thomas Register and Dun & Bradstreet. The size of some companies could not be determined even after this research.