

Patent regimes and R&D: A firm level study of the Semiconductor industry

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Abstract

This paper studies the patenting and R&D behavior of firms in the Semiconductor Industry. I look at both the aggregate and the disaggregated data for firms in this industry. The aggregate data shows that the “patent paradox” is present at the industry-level, similar to the results reported by Hall and Ziedonis (2001) in their seminal empirical paper. The disaggregated data shows that the paradox is more prominent among the smaller firms. Number of patents per R&D dollar has remained more or less flat for the large firms, while that for the smaller firms have increased in the 1980s following the strengthening of the U.S. patent regime. On the other hand, firms in this industry have not changed their R&D behavior noticeably after the strengthening of the patent regime. These observations raise questions regarding the channels through which the incentives given by a strong patent regime work and whether the strength of the patent regime plays an important role to stir innovation in this industry.

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1 Introduction

Beginning in the early 1980s, substantial changes were introduced in the U.S. patent system. Efforts were made at the legislative level to strengthen the intellectual property regime. With the formation of the Court of Appeals for the Federal Circuit (CAFC) in 1982 the U.S. patent system moved towards that goal. The stated purpose for the formation of CAFC was to consolidate the judicial process for treating cases related to patent disputes.² The formation of CAFC, together with other legislative changes, have strengthened the U.S. patent system in favor of the patent holders.³

In addition to studying the legal aspects of this pro-patent regime shift researchers have looked at the effects of this change on firms' patenting and R&D decisions. Kortum and Lerner have looked at the aggregate U.S. patent and R&D intensity data from 1980-1999. They have found that R&D intensity increased substantially after 1982 but has flattened during the 1990s. During the same period, however, patenting has increased substantially. Hall and Ziedonis (2001)

²According to the Federal Judicial Center's web-site (<http://www.fjc.gov/>) "In an effort to promote greater uniformity in certain areas of federal jurisdiction courts of appeals for the regional circuits, the Congress in 1982 established what is now the only U.S. court of appeals defined exclusively by its jurisdiction rather than geographical boundaries."

³For a detailed discussion see Adelman (1987), Merges (1992).

also observe the same set of facts for the semiconductor industry. Their data from 1979-1995 shows that patenting have surged during the same period when trend for the industry R&D has remained more or less the same. This is referred to as the *patent paradox* in the literature.

The strengthening of the patent regime was meant to provide an incentive mechanism which will enable firms to commit to increased innovative activities. The patent paradox raises questions regarding the effectiveness of a stronger patent regime in delivering more innovation, at least for the semiconductor industry. The paradox of increased patenting without increased R&D is observed in the aggregate data for this industry but, to my knowledge, no one has yet looked at the data at a more disaggregated level. A next logical step is to understand the composition of these aggregate data and to see whether the firm-level decisions are related to the firm size. If firms of different sizes are found to behave in similar ways with respect to their patenting and R&D then the policy implication of a stronger patent regime will be different than if the firms of different sizes are found to behave in different ways.

In this paper I look at the data from the firms in the semiconductor industry. The data set is extensive and includes 164 firms for a period of 24 years. I create firm-size categories according to various criteria to see if there is any size effect.

In the aggregate data I find that the patent paradox is prominently present. These findings corroborate those in Hall and Ziedonis' paper. I also find that firm size do matter: smaller firms seem to be getting more patents per dollar of their R&D as compared to the larger firms in the industry after the change in the patent regime. On the other hand R&D per employee remains unaffected by the change in the patent regime for firms in all firm-size categories. These observations raise question regarding the efficacy of the new patent regime in inducing higher levels of innovation, at least in the context of the semiconductor industry.

In the next section the characteristics of the semiconductor industry in U.S. is discussed briefly. In section 3, the data is presented. Section 4 concludes.

2 The Semiconductor Industry

In this paper the semiconductor industry is identified by the SIC code 3674. This industry is also referred to as the "semiconductor and related devices".

2.1 The main categories of firms and innovation activities

There are broadly three different kinds of firms in this industry. The first group (the "captive suppliers") consist of the vertically integrated firms, like IBM, that

produce semiconductor devices mostly for internal use. The second group (the “merchant suppliers”) consist of independent firms, like Intel, that have fabrication plants and supply semiconductor devices to other firms. The third group (the “design firms”) consist of firms that do not own a fabrication plant, but “... specialize in different innovative products...”.⁴ The design firms generally contract out the manufacturing part to other firms.

Innovations can take place in a variety of different areas, including in basic scientific research, in the numerous manufacturing steps, in testing equipments and in packaging. The industry produces a wide range of innovations from easily patentable (and enforceable) process patents to highly complex and hard to patent circuit designs. Some of the major scientific and engineering innovations in this industry are listed in appendix A, to show the wide range of innovation activities that have taken place over the last sixty years.

2.2 The U.S. Government’s role

Although the main source of research and development expenditure in the semiconductor industry has been the private sector, the U.S. Government has also played an important roles in the development of this industry in two different

⁴Hall and Ziedonis (2001).

ways. The U.S. Government, particularly the military, has actively encouraged re-search during the entire period from 1955 to the late seventies by its very generous procurement policies. Levin (1982) in his survey of the semiconductor industry discusses the procurement policies and other acts of providing subsidized R&D by the Government in great details. He reports that the specific needs of the various branches of the U.S. military provided a boost to the development and refinement of silicon transistor technology and integrated circuits during the 50s and the integrated circuit technology during the 60s. The U.S. military also indirectly affected the diffusion of various semiconductor technologies by practicing “second sourcing”.⁵ Second sourcing was helpful in diffusing advanced technology and in creating suitable conditions for entry by new firms.

The Government also played an important role in the semiconductor industry research by providing public funding to research in the basic sciences. These funding came via NASA, the National Bureau of Standards and the National Science Foundation. The Government also supported research laboratories in private firms between 1950-1970. Levin (1982) notes that the flexibility and the responsiveness of Government’s R&D support during the this entire period has been

⁵“Second sourcing” refers to the military practice of generally relying on more than one source to deliver important weapon systems. This practice helped lower the risk of failure for crucial weapons systems.

crucial to the development of the semiconductor industry.

2.3 Property rights

The industry has traditionally not enforced property rights very strongly. The cumulative and complex nature of the industry makes it almost impossible for the participant firms to innovate without infringing some other firms' patents. Firms in this industry try to get around the infringement issue by entering into general licensing and bilateral contractual arrangements, called cross-licensing, which enable the firms to produce freely without worrying about legal problems.⁶

Licensing and cross-licensing is very common in this industry. The formation of RCA (Radio Corporation of America) in 1919 to break the deadlock over complementary patents held by different innovators was one of the earliest examples of cross-licensing in this industry. Even firms that compete aggressively in the product market, like Intel and AMD, have a long history of engaging in cross-licensing agreements. The relative importance of licensing and cross-licensing in

⁶Cross-licensing is a particular type of bilateral licensing, where the contracting parties agree to license all patents owned by each in a particular field-of-use. In semiconductor industry, cross-licensing often does not involve any actual transfer of knowledge and/or any payments to the relevant parties. It just ensures that firms have the legal right to access each other's patented innovations related to a particular field-of-use.

this industry is reported by Anand and Khanna (2000). They report that out of all the contracts made by computer and electronics firms around 40% are made among related firms, as compared to 28% for Chemicals and 23% for other industries. They also report that “..cross-licensing are more commonly observed in Electronics (20%), where most of the deals concern semiconductor technologies. In other industries, the incidence of cross-licensing is much lower (about 10%).”

The bargaining power of a firm in a licensing arrangement depends crucially on its patent portfolio. Patent portfolios are often used in the industry as bargaining chips to get favorable positions in cross-licensing and other private contractual arrangements. After the strengthening of the U.S. patent regime it has become more important for firms to have legal rights over using innovations that are patented by other firms. A stronger patent regime has made infringement costly. Firms with important patented innovations are now in a better position to sue other firms that use their innovations to develop products. A patent infringement suit has the potential of creating hold-ups for firms that are trying to launch new products. To avoid costly hold-ups, firms are preemptively building up large patent portfolios which they are using to negotiate better access to other firms’ innovations and to obtain favorable licensing and cross-licensing payment arrangements. Cohen, et al (2000) have reported that the new patent regime has created

an enhanced incentive for higher patenting — patenting for bargaining purposes.⁷ Grindley and Teece (1997) also observe that “Coincident with the increased importance of patents is the increased importance of licensing and cross-licensing. Cross-licensing has become a significant dimension of competition.” The importance of patents have magnified because of their strategic importance in licensing. As a result, semiconductor firms are now patenting more aggressively.

3 The Data

In this paper I look at the data from the semiconductor industry to assess the effects of the pro-patent regime shift on firm’s patenting and R&D decisions. As mentioned before, the U.S. patent regime change was introduced with the understanding that stronger intellectual property rights will enhance firms’ incentive to choose higher levels of R&D. It is reasonable to assume that the regime change will have different impact on the decision process of the firms in different industries. The purpose of this section is to study the impact of the patent regime change on the semiconductor industry. Here I look at the aggregate R&D and patenting data. I also look at the these data at a more disaggregated level, to understand

⁷See Cohen, Nelson and Walsh (2000). They report this after talking to the intellectual property managers from several firms.

whether firm-level characteristics play any role in determining the trends in the aggregate data.

For this study I only consider the merchant supplier firms and the design firms. The reason for excluding the captive suppliers is because large multi-product captive suppliers, like IBM, report their total R&D. From the total R&D data it is not possible to extract the amount of R&D expenditures these firms incur in developing semiconductor devices. Hence the large captive suppliers are excluded in this exercise, although it is well-known that these firms incur substantial expenditures in semiconductor device related research.

Firm level R&D, employment, sales and capital data are obtained from Compustat. A sample of 234 publicly traded semiconductor firms is initially considered. The data set spans twenty four years from 1979-2002.⁸ The firms in my data set have been matched to the *assignee number* developed by Hall, Jaffe and Trajtenberg (2000). About 30% of firms in the data set have either changed their names or have merged with an existing firm. Those firms are identified by cross-referencing all the names of the firms in the sample with Lexis-Nexis. After adjusting for these changes I am left with 164 firms.

The patenting data is obtained from two sources. The patent data for the sam-

⁸1979 is chosen because before that there were too few firms in the semiconductor industry.

ple of 164 firms between 1979-1999 are extracted from data file provided by the Hall, et al. Next, new data is collected for these firms from the USPTO website and the two are compiled together to give the patent data set from 1979-2002.

All patent data reported here are patent application data. The reason for reporting the application data and not the grant data is because this paper deals with the patenting decision that a firm makes once it has obtained a patentable innovation. What is, therefore, more important for this analysis is to get a patent count that is as close to the timing of innovation as possible. The patent application date is definitely more close to the timing of the innovation than the patent grant date.⁹ Also, following the TRIPS agreement (1994), which aimed to integrate the intellectual policy regimes among the member countries of WTO, it is more likely that innovators would want to apply for patents quickly once they have a patentable innovation, thereby reducing the gap between timing of innovations and the patent application date even more.

The list of firms in my sample and how I chose these firms are presented in appendix B.

Below I highlight some facts observed from the data:

⁹Patent grant dates may depend on a number of factors, like the nature of the product, availability of USPTO patent reviewers for that particular technical area, etc. These factors have little to do with a firm's internal decisions.

- **Fact 1:** After 1985 the increase in the number of firms who have applied for large number of patents has been greater than the increase in the number of firms who have undertaken large R&D expenditures.
- **Fact 2:** Both aggregate patenting and aggregate R&D have grown relative to the size of the industry, but patenting per employee has shown a sharper growth after 1982 compared to the growth of R&D per employee.
- **Fact 3:** For large firms the growth of patenting per R&D and R&D per employee have changed in a way that conforms with the notion that these firms' decision making process remained relatively unaffected by the changes in the patent regime. The *patent paradox* effect (higher patenting, unchanged R&D) is more prominently observed among the medium and the small firms.

The data is presented in the next section.

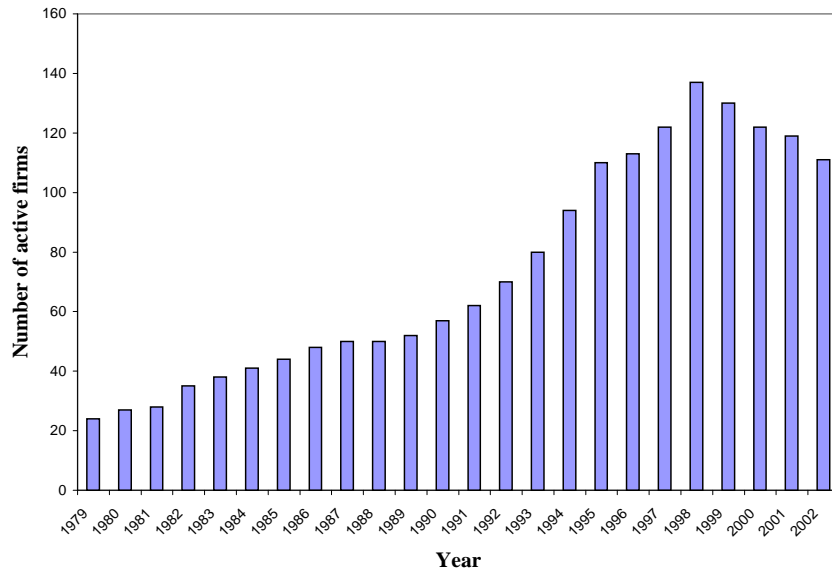


Figure 1: Number of active semiconductor firms from 1979 to 2002

3.1 Distribution of firms

In 1979 a total of 24 firms were active in the semiconductor industry.¹⁰ By 2002 the number of active firms has increased to 111. Figure 1 shows the number of active firms each year between 1979-2002. The data shows that the number of firms in the industry has changed substantially between 1979 and 2002. The average growth rate of firms in this industry is 7.2%. The growth rate of number

¹⁰Active firms for a certain year are those that have at least one non-zero entry in the Compustat data set. So if a firm shows a non-zero value for any of its firm-specific variables for a certain year, then that firm will be counted as an active firm for that year. All other firms will be considered inactive.

of firms have decreased to an average of 5% after 1998.

To look more closely at the change in the distribution of firms in terms of patenting, I divide all firms into several categories in terms of their total patent applications. The categorization criterion is based on the year 2000 data. The categorization is fixed over all the years, and the firms are allowed to change groups. Each firm in each year must belong to one of the four categories — i) very large firms (>500 patent applications annually), ii) large firms (100-500 patent applications annually), iii) middle-sized firms (10-100 patent applications annually), iv) small firms (<10 patent applications annually). Number of firms in each patent-size category between 1979-2002 is presented in figure 2. Figure 2 shows the changes in the share of firms in each patent-size category over time. Number of firms that applied for less than 10 patents per year (small firms) has increased by 5.6% between 1979-2002, while their share has fallen from 0.88 to 0.59. The number of middle and large firm has increased by 17.1% and 14.5% respectively, and their shares have increased from 0.08 to 0.3 and from 0.04 to 0.08 respectively. The number of firms that applied for more than 500 patents per year (very large firms) has increased from 0 in 1979 to 4 in 2002 and their share has increased from 0 to 0.04. If the entire period is divided into two sub-periods, before 1986 and after 1986, the growth rates of each firm-size category for each

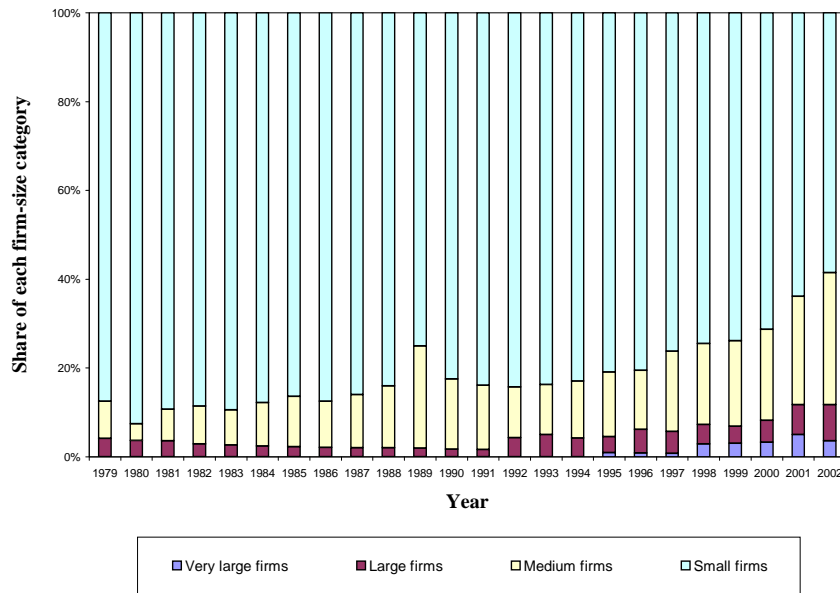


Figure 2: Share of firms in each patent-size category (1979-2002)

of the two periods are given in table 1.

	1979-1986	1986-2002
Small firms	10.7%	3.3%
Medium firms	22.6%	14.7%
Large firms	0%	20.8%

Table 1: Average growth rate of number of firms in each patent-size category

Table 1 shows that the size-distribution of firms in terms of patenting have shifted in favor of larger firms after 1986. The percentage increase in the number

of large firms is greater after 1986, while the percentage increase in the number of firms in both the medium and small categories has fallen after 1986. This affirms observations made by other researchers that firms in the semiconductor industry are patenting at a higher rate after the pro-patent reforms of the early 1980s.

I also divide all firms into several categories in terms of their total real R&D expenditure. The categorization is fixed over all the years and firms are allowed to change groups. Each firm in each year must belong to one of the five categories: — i) very large firms ($> \$500$ millions in real R&D annually), ii) large firms ($\$100$ - 500 millions in real R&D annually), iii) middle-sized firms ($\$10$ - 100 millions in real R&D annually), iv) small firms ($< \$10$ millions in real R&D annually). Number of firms in each R&D-size category between 1979-2002 is presented in figure 3. Figure 3 shows that the number of small firms has increased by 4.3%, while their share has fallen from 0.83 to 0.41. The number of middle and large firms has increased by 17% and 12.6% respectively and their shares have increased from 0.08 to 0.41 and from 0.08 to 0.14 respectively. To understand whether there has been any change in firm-size pattern (in terms of R&D) after the change in the patent regime, the entire period is divided into two sub-periods, before 1986 and after 1986. The growth rates of each firm-size category for each of these two periods are given below.

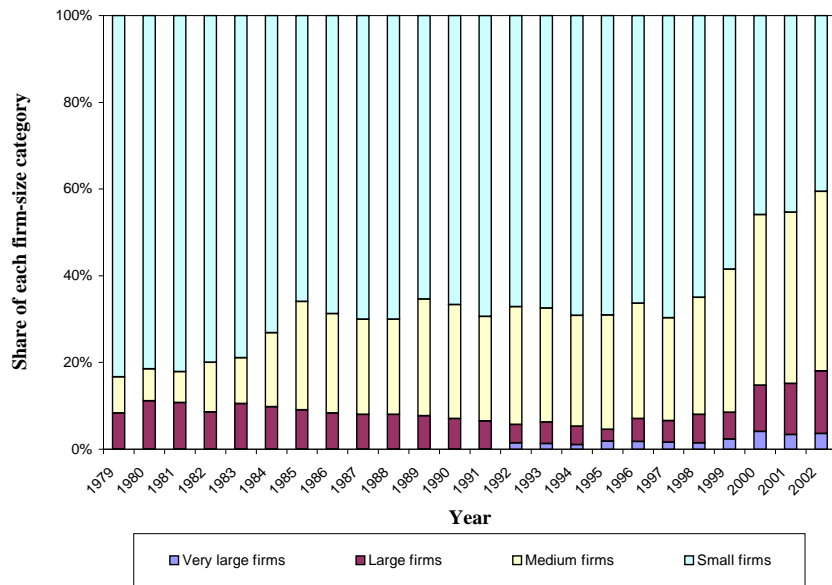


Figure 3: Share of firms in each R&D-size category (1979-2002)

	1979-1986	1986-2002
Small firms	7.7%	2.8%
Medium firms	33.2%	9.9%
Large firms	11.9%	12.9%

Table 2: Average growth rate of number of firms in each R&D-size category

Table 2 shows that while the growth rates for the small and middle firms have decreased substantially after 1986, for the large-firm category the growth rate has increased only slightly. When taken together with the previous firm-size data (ac-

ording to the number of patent applications), table 2 suggest that after 1986 more and more firms are qualifying as large firms in terms of their patent portfolios, but there has not been a large increase in the number of firms who are choosing high levels of R&D. This is what I have referred to as fact 1 before.

3.2 Patenting and R&D data

Figure 4 shows the total number of patent applications and the total real R&D expenditure for all the firms in my sample between 1979 and 2002. The two time-series show that while both aggregate patenting and aggregate R&D have grown over time, aggregate patenting has grown at a faster rate than aggregate R&D. The growth in aggregate R&D, in fact, slowed down in the period between 1984 and 1992. On the other hand, the growth in patenting has been steady.

To get an ideas about the growth of patenting and R&D relative to the size of the industry, I look at the patenting per employee and R&D per employee time series. These are shown in figure 5. The size-adjusted data shows the same pattern observed in the aggregated raw data — both patenting per employee and R&D per employee have grown over time, but the growth rate of patenting per employee is higher than that of R&D per employee. Also the growth rate for patenting per employee have increased after 1982, while that for R&D per employee has slowed

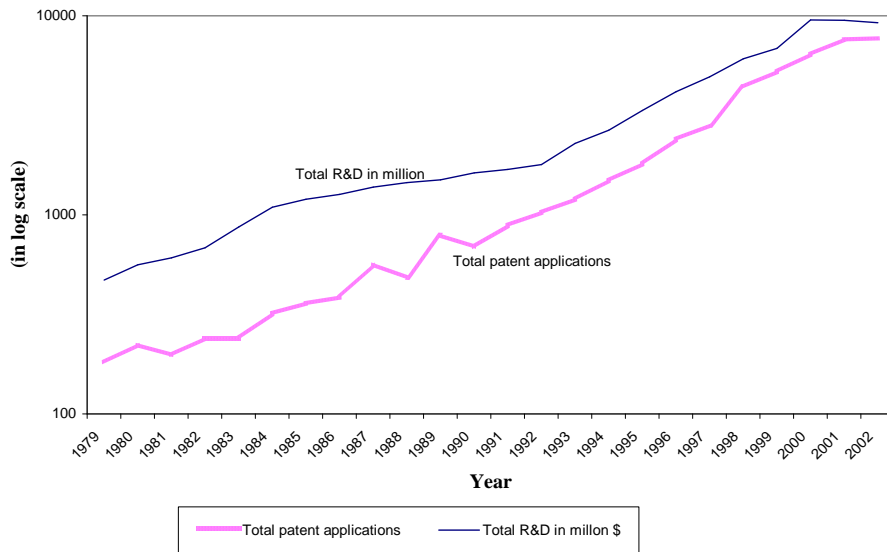


Figure 4: Aggregate patenting and R&D in the semiconductor industry

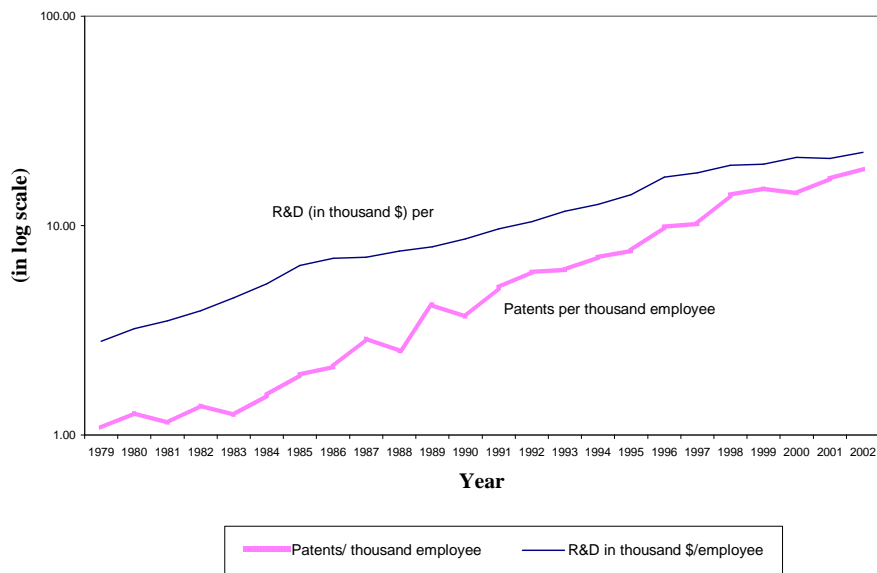


Figure 5: Patents per employee and R&D per employee

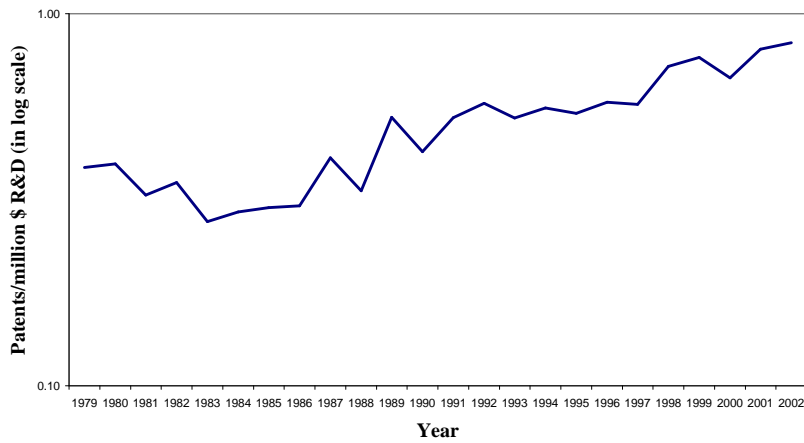


Figure 6: Patent applications per million \$ R&D

down after 1985. This is what I have referred to as fact 2 before. The observations made here corroborate the results of the previous empirical literature.

Another way to look at the patenting phenomenon is to study the changes in patenting efficiency, i.e., what is the relative size of patenting relative to R&D. Figure 6 shows the patent per real R&D \$ data for the industry. The data shows that after 1983 (and more prominently after 1986) the total patenting for the industry has risen faster than the total R&D, so that the ratio of the two has changed. This is one more way of showing that after 1983 this industry as a whole is patenting more compared to its aggregate R&D (fact 2).

3.3 Data for different firm-size categories

In this section I categorize firms in different size-categories according to various firm-specific criteria and study the R&D and patenting decision of firms in each of these size groups. The idea behind this exercise is to look beyond the aggregate industry-level data and try to understand whether firm-level decisions are functions of firm-size.

Firm-size can be determined in quite a few number of ways. The total employment numbers, size of the R&D expenditure, and sales are some commonly used criteria. On the other hand, firms can also be categorized according to the number of patents they have applied for in a particular year. This particular size criterion, though somewhat unorthodox, is relevant in the context of this paper. It will help us understand whether firms who have applied for a large number of patents in a particular years have also behaved differently in terms of their patent applications and R&D decisions and whether they have been affected differently by the change in the patent regime as compared to the smaller firms.

The discussion in the next subsection is based on firm-size categories determined by the number of patent applications. In the subsequent sections I will use other criteria for determining firm-size, such as R&D expenditure, number of employees and sales figures.

3.3.1 Firm-size by the number of patents

The size criterion are determined by looking at the data from the year 2000. Based on that data, firms with more than 100 patent applications are considered large; firms which have between 10 and 100 patent applications are considered medium sized and firms with less than 10 patent applications are considered small. The size criterion remains the same for all years.

A careful look at the firm level data reveals that the pattern of R&D and patenting is somewhat different for the large firms as compared to the medium and the small firms in this industry. In figure 7 the patent per \$ of R&D data is reported. The patent per \$ of R&D is a measure of patenting efficiency — an increase suggests that firms have become more efficient producers of patents for every dollar of investment in R&D. Although all the three firm types show increasing patenting per dollar of R&D till 1992-93, the increase is the most prominent for the medium and small firms. The patenting per dollar of R&D has remained relatively flat for the large firms even after the change in the patent regime. The medium sized firms have shown the strongest continuous growth in patenting efficiency till 1998. The patenting efficiency of the smaller firms has increased after 1983 and has shown strong growth till 1992 after which the patenting efficiency has fallen drastically. The semiconductor industry as a whole experienced downturn during 2000-2001,

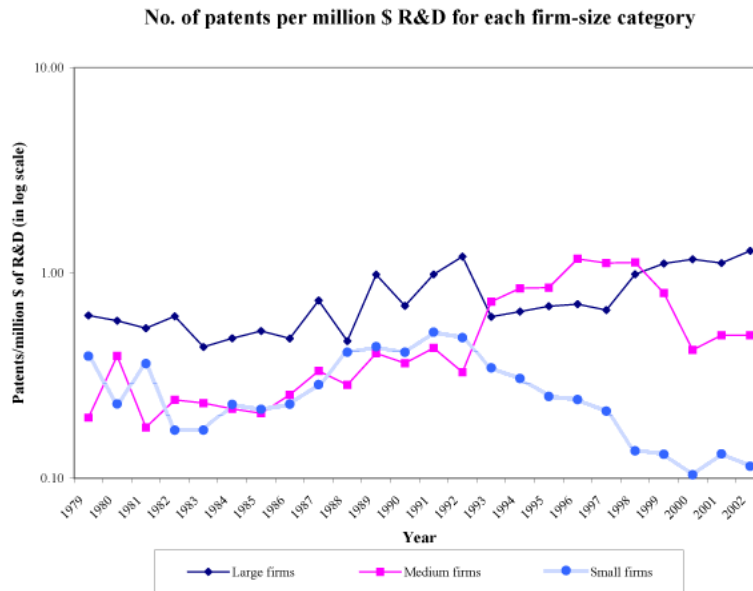


Figure 7: Patents per R&D \$ for different firm-size categories

which might be an important reason for the poor performance of some firms. The timing of the reduction in patent efficiency in small firms starting from 1992 suggest that this might have some relation to the global recession of the early nineties.

A look at the average patenting efficiency for each of the three firm-size categories (figure 8), however, shows a slightly different picture. The average patenting efficiency of medium firms seems to have fallen after 1983 and the fall continues throughout the entire period in the sample. Both large and small firms have shown increased patenting efficiency after 1983, but large firms seems to be much better (in terms of levels) in converting R&D dollars into patents. After

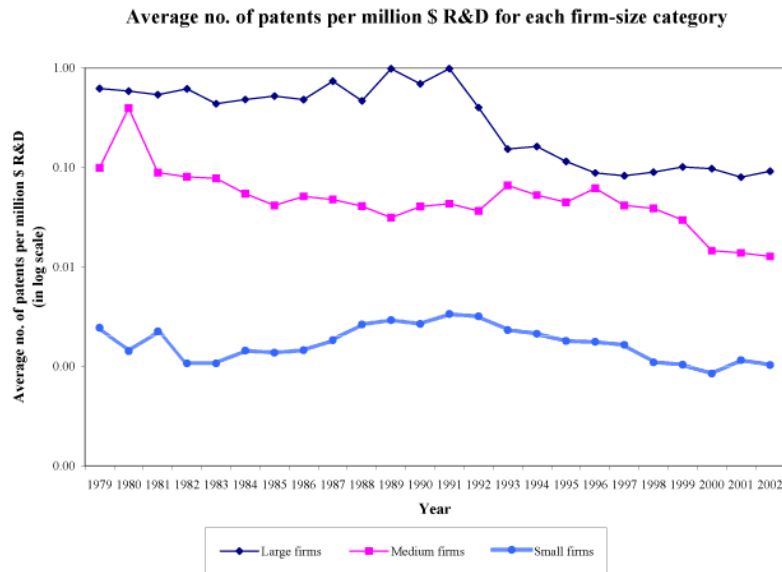


Figure 8: Average no. of patents per R&D \$ for different firm-size categories

1992, both large and small firms have shown decreased patenting efficiency, but the fall for the large firms are more substantial. The average patenting efficiency of small firms is relatively flat over the entire period. One reason for the fall in average patenting efficiency for the large firms can be that a lot of firms started patenting heavily in the late nineties and moved from the medium-size category to the large-size. The increase in the number of large firms (in terms of patent application) depressed the average value of patenting efficiency.

A look at the R&D per employee data (figure 9) for the three firm-size categories show that the small and large firms have not changed their R&D behavior significantly after 1982-83. The stronger patent regime did not have a noticeable

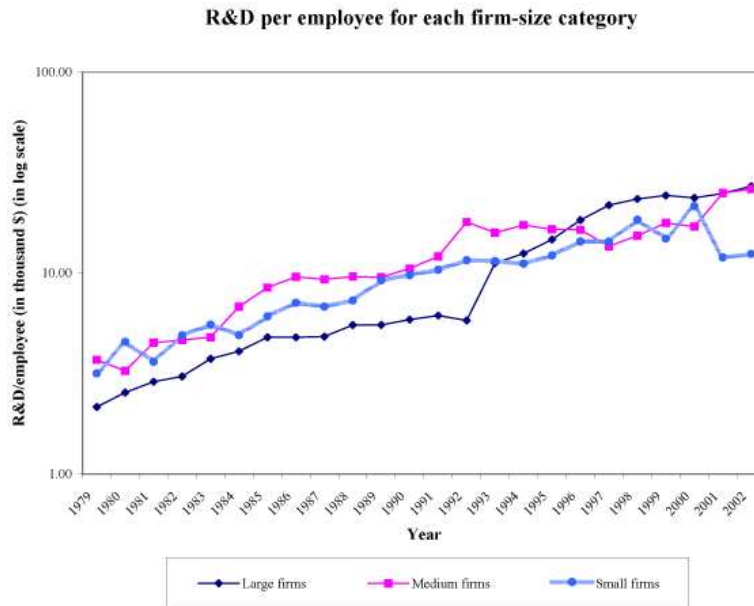


Figure 9: R&D per employee for different firm-size categories

impact on R&D expenditure of these firms, contrary to the expectation of the policy makers. The medium firms, however, have increased their R&D per employee and have continued to do so till 1992, after which the R&D per employee has been more or less flat.

Figure 9 suggests that while the R&D decision of large and small firms were unaffected by the change in the patent regime, the same does not hold for the medium firms. One hypothesis could be that a weak patent regime had a larger negative impact on the medium sized firms because, unlike the large firms who have other instruments at their disposal (like, a better bargaining position vis-

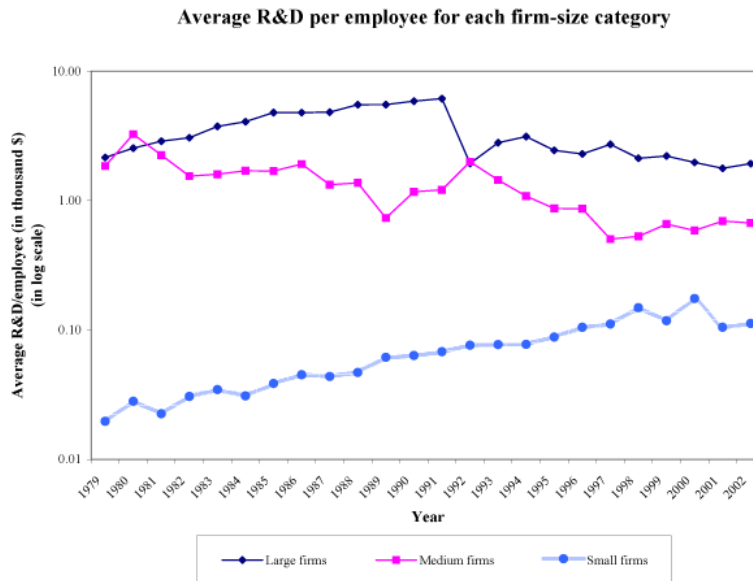


Figure 10: Average R&D per employee for different firm-size categories

a-vi other firms, as observed by Cohen, et. al (2000)) to protect their intellectual property, the medium sized firms rely more heavily on the patent system to protect their innovations. A stronger patent regime, therefore, provided the medium-sized firms with the required incentive system that they needed to increase their investment in R&D. But this does not explain why the R&D per employee for the small firms did not change after 1982-83.

In figure 10 we look at the average R&D per employee for each firm size category. It shows that none of the three firm-size categories significantly changes in their R&D expenditures after 1982-93. The large firms have increased their level

of R&D continuously till 1991 after which it has fallen quite sharply. The medium sized firms have maintained a relatively flat R&D per employee, while the small firms have continuously increased their R&D per employee. If a stronger patent regime has indeed changed the incentive of firms to engage in more innovation, it is not clear from looking at the average R&D data.

Figure 7 and 9 suggest that the *patent paradox* is more relevant for middle and small sized firms in the industry. The change in the patenting efficiency for the large firms have been small and the timing does not coincide with the change in the U.S. patent regime while the timings of the increase in patenting efficiency for the small and the medium firms do match quite closely. The small and the medium firms are generating an increased number of patents per dollar of R&D expenditure after the change in the patent regime. The aggregate behavior of the semiconductor industry, which is patenting more with not much more of R&D, seems to be driven mostly by these firms. The patenting and R&D decisions of large firms are also paradoxical, in a different sense. They are more or less unaffected by the change in the patent regime and more receptive to changes in the external environment.

The disaggregated patenting and R&D data from the semiconductor industry casts a shadow of doubt over the traditional argument for having a strong incentive

system in the form of a strong patent regime to encourage R&D. Even though all the three groups are not behaving in similar fashions with respect to their patenting and R&D decisions, none shows a sharp increase in R&D in response to a stronger patent regime.

The data also raises question about the decision making process of firms in different size categories. Do the large firms have a fundamentally different R&D strategy as opposed to the other firms and, if so, why? One hypothesis could be that the non-receptiveness of the large firms is due to the internalization of the externalities arising from an imperfect patent regime. Large firms generally have a larger and wider patent portfolio which allows them to be in a better bargaining position when it comes to either protecting their valued intellectual property or gaining access to others'. That is why their patenting efficiency is less affected by the change in the patent regime as compared to the small and the medium firms.

3.3.2 Firm-size by R&D Expenditure

In the previous section firm-size categories were based on the number of patent applications. To see whether the same kind of results hold when other criterion for determining firm-size is applied, I categorize firms according to the size of their real R&D expenditure in this section. As in the previous case, the size categories

are picked by looking at the data from the year 2000. Firms with more than 100 million dollars of real R&D expenditure annually are classified as large; firms with R&D expenditure between 10-100 million dollars are classified as medium sized firms, while firms with less than 10 million dollars of R&D expenditure are classified as small sized firms.

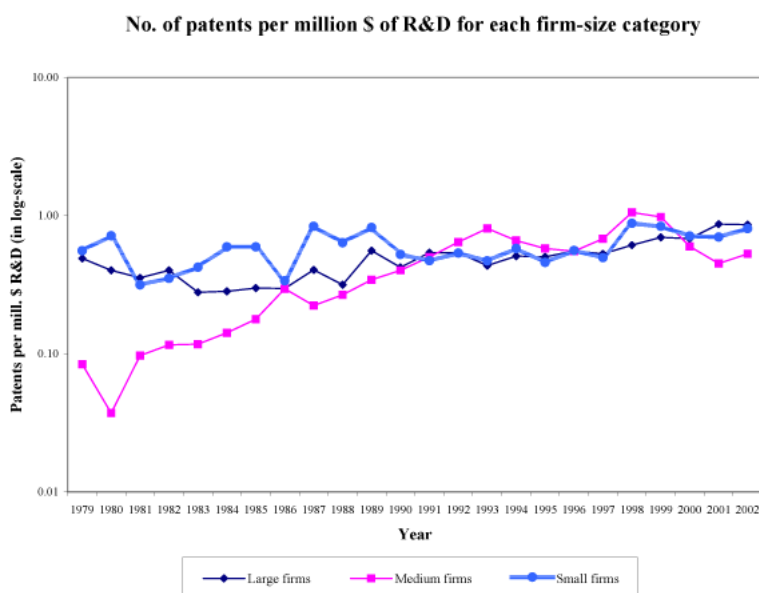


Figure 11: Patents per R&D \$ for different firm-size categories

In this case the patents per dollar of R&D show similar trend as in the previous case. As shown in figure 11, the large firms maintained an almost unchanged level of patents per dollar of R&D for the entire period. The medium size firms showed the largest increase in patenting efficiency, but the trend flattened somewhat after 1993. The patenting efficiency of the small firms increased after 1986, but

maintained a flatter trend after 1990. However, the average number of patents per dollar of R&D shows a different picture (figure 12). Average patenting efficiency remained flat for all firm-size categories for almost the entire period in the sample.

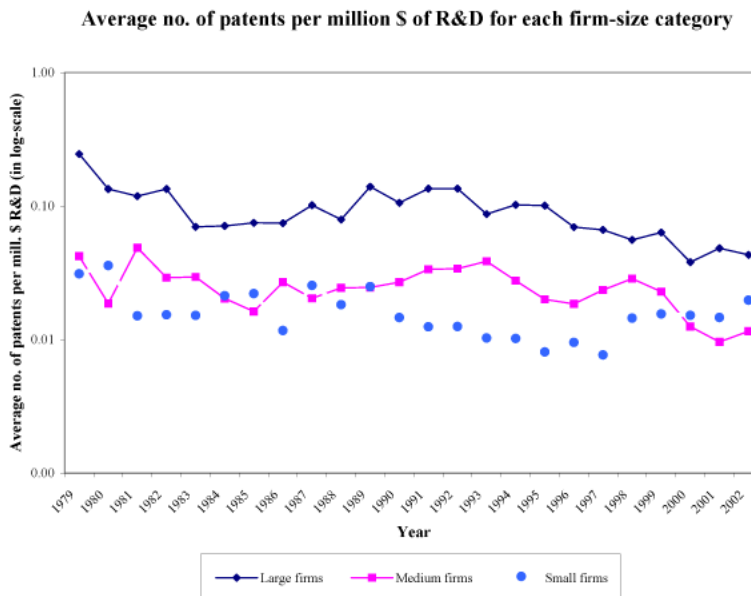


Figure 12: Average no. of patents per R&D \$ for different firm-size categories

The R&D per employee data also shows trends very similar to the previous case. As shown in figure 13, the small and the large firms have not changed their R&D behavior significantly after 1982-83, while the medium firms seems to have increased their R&D after 1984.¹¹

¹¹It is possible that 1984 was an anomalous year. If the dip in R&D for 1984 is ignored then it is hard to see that the change in the patent regime has led to substantial changes in the R&D behavior of the medium-sized firms.

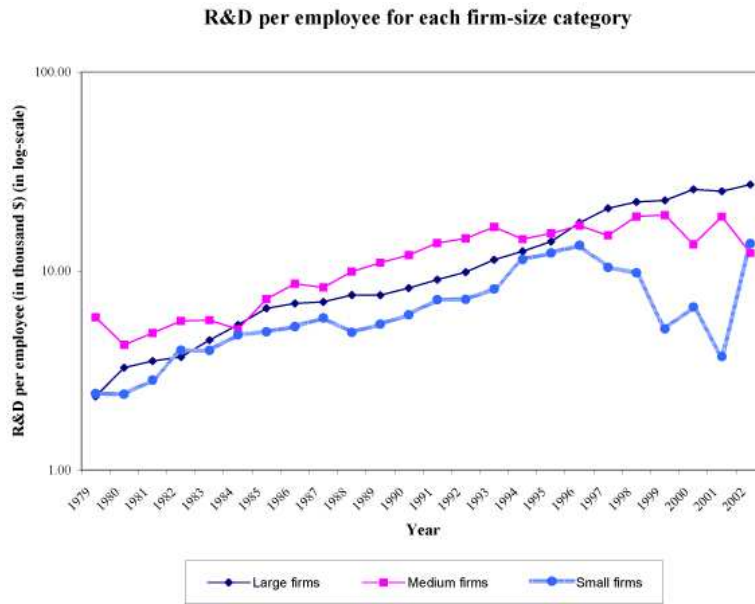


Figure 13: R&D per employee for different firm-size categories

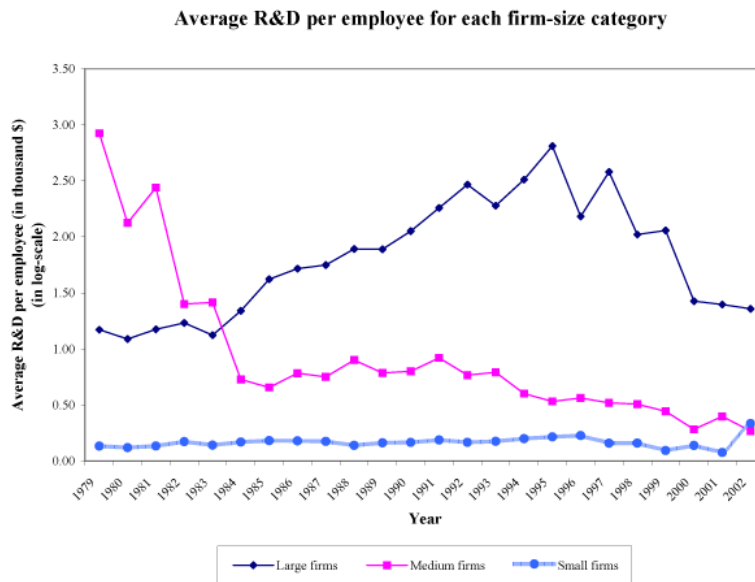


Figure 14: Average R&D per employee for different firm-size

In contrast the average R&D per employee for the medium firms have fallen sharply through 1984, while that for the large firms have increased after 1983 (figure 14).

3.3.3 Firm-size by other criteria

Data on different firm-size categories according to employment levels is reported in this section. Data according to sales-size is reported in appendix C.

The patenting efficiency and R&D per employee for different firm size categories according to employment numbers are shown in figures 15 and 16. Firms with more than 3000 employees are considered large; firms which have between 500-3000 employees are considered medium and firms with less than 500 employees are considered small.

In this case the change in patenting efficiency is relatively small for the small firms as compared to the other groups, although in terms of levels it remains the highest. The average patenting efficiency and average R&D per employee are given in figures 17 and 18.

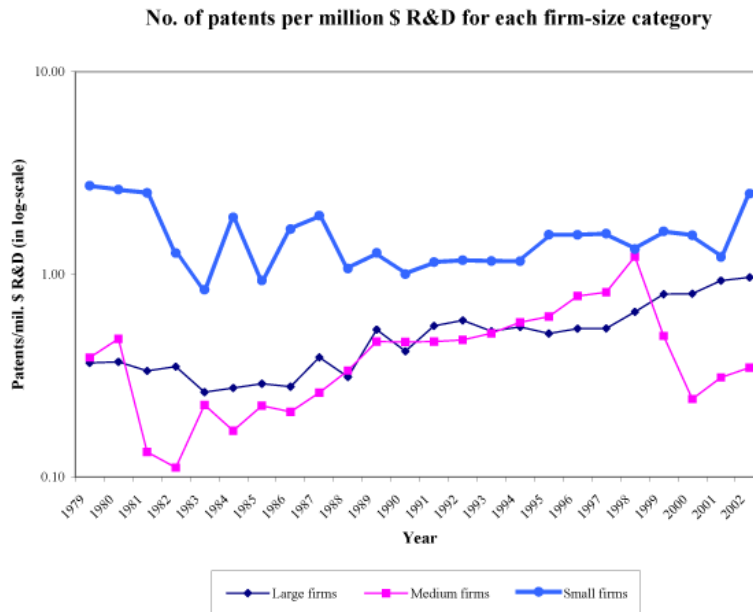


Figure 15: Patents per R&D \$ for different firm-size categories

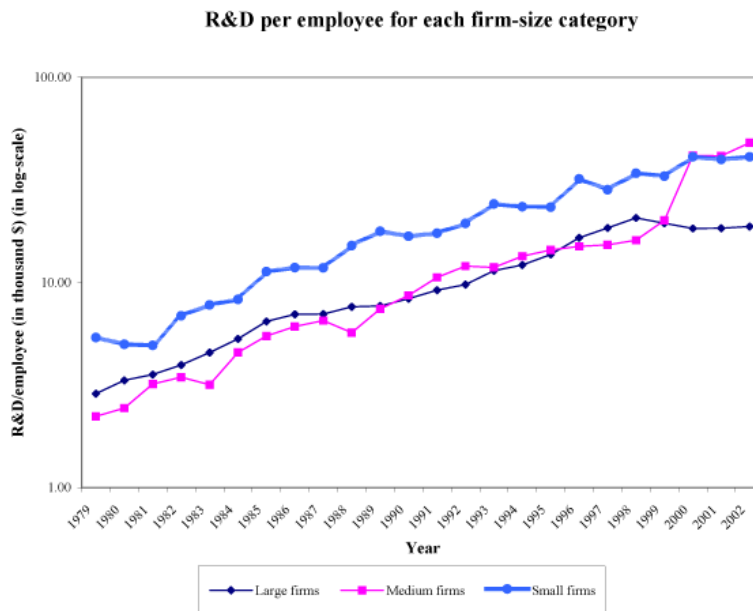


Figure 16: R&D per employee for different firm-size categories

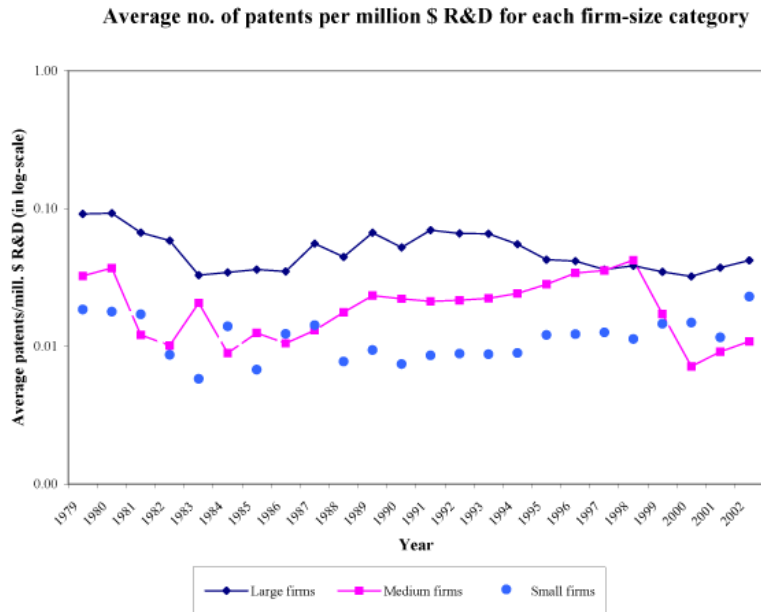


Figure 17: Average no. of patents per million \$ R&D for different firm-size

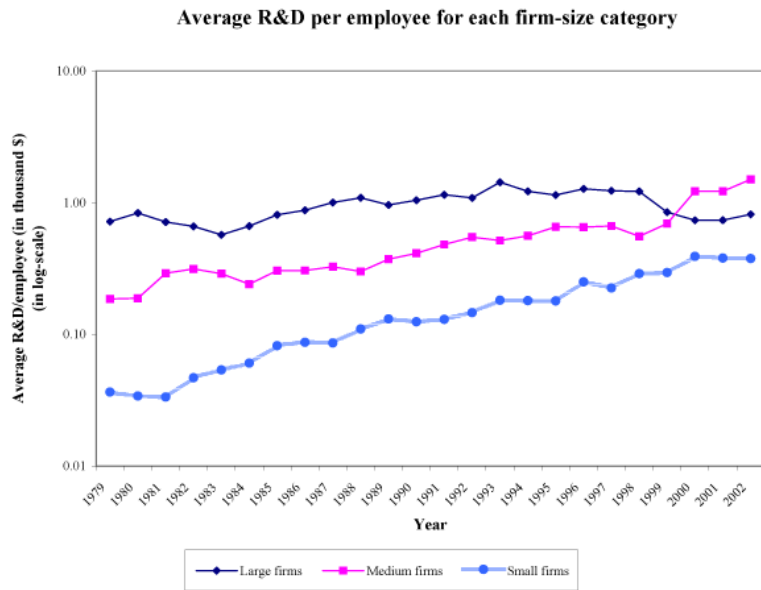


Figure 18: Average R&D per employee for different firm-size categories

The R&D behavior shows similar trend as in the previous cases, with no distinct changes following the early 1980s change in the patent regime.

4 Conclusion

The pro-patent regime shift in the U.S. after 1982 has affected the patenting and R&D behavior of semiconductor firms, but not exactly in the way envisioned by the policy-makers. The level of R&D chosen by firms seems to have very little correlation to the strength of the patent regime, since firms have not shown any discrete change in their R&D expenditure in response to the new patent regime. On the other hand, the new regime have prompted medium and small firms in this industry to increase their patent portfolio.

The semiconductor is a cumulative industry. Firms depend on each other's innovations to develop their final products. If strategic considerations are crucial for firm-level patenting and R&D decisions, then the implications of a strong patent regime in a highly cumulative industry will be different than what the policy-makers had envisioned. Dey (2006) shows that a lowering of patenting cost (i.e., a stronger patent regime) can lead to a situation where firms strategically increase their patent portfolio, which helps them at the licensing stage, while keeping their

R&D expenditure relatively unchanged. The patent policy regime, in that case, acts as a proxy for how much ease with which innovations can be informally shared in an industry—a stronger regime essentially shutting down informal sharing. The end-result is that a strong patent system may not be innovation-friendly in the context of the entire industry.

If the new patent regime has made a large patent portfolio an essential tool for fostering technology acquisition and sharing, then the smaller firms with a smaller patent portfolio will be at a disadvantage. The observation that smaller firms are ramping up their patent portfolio may be because of this. A large number of patents, on the other hand, is likely to create barriers to new innovation and reduce some firms' incentives to conduct certain types of research, due to the high cost of negotiating with a large number of players and the possible hold-up problem. This raises questions regarding the efficacy of the current patent regime in the U.S.

A number of researchers have started to ask this question and some have suggested particular reforms of the patent system. A growing concern is that the average quality of patents granted has fallen, as the patent-count has sky-rocketed. Barton (2000) suggest stricter standards for granting patents and having a mechanism to get rid of invalid patents. A report by the Federal Trade Commission in 2003 also takes a strong stand against “questionable patents” claiming that these

patents can stifle innovation particularly in industries where innovation is cumulative. The FTC report also suggest increased funding for USPTO and enhanced examination rights to the patent examiners.¹² The coming years might see another set of changes in the U.S. patent regime.

The different patenting and R&D trends between different firms are also the product of their internal organizational structures, which is a determinant of the internal incentive mechanisms. Large, multi-product firms are likely to have different organizational structure than the small, design firms. To have a comprehensive understanding of why firms of different size are behaving differently it is important to understand the structural differences at a micro level. A detailed micro-level analysis of individual firm strategies should help us address some of the behavioral patterns observed at the aggregate level.

¹²The full FTC report can be found at <http://www.ftc.gov/os/2003/10/innovationrpt.pdf>

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**Appendix A: A partial list of important innovations
in the semiconductor industry (1940-2000)**

Year	The Innovation
1947	Bell Lab invents transistor.
1948	Bell Lab grows single crystal of Germanium.
1952	Western Electric starts commercial production of junction transistors.
1952-53	Techniques for developing surface barrier transistor developed at General Electric, Western Electric and Philco.
1958	Planar Process developed at Fairchild Semiconductor.
1960	AT&T invents modem.
1961	Texas Instruments builds first IC computer.
1970	Intel introduces DRAM.
1971	Intel introduces 8-bit microprocessor.
1973	National Semiconductor introduces 16-bit microprocessor.
1975	First PC goes to the market.
1977	Hayes Corp. invents first PC modem.
1979	Motorola introduces the 16-bit processor.
1980	Bell Lab introduces 32-bit microprocessor.

Year	The Innovation
1981	LSI Logic develops the first semi-custom chip.
1981-82	First portable computer goes to the market.
1984	Xilinx develops completely customized chips.
1986	Bell Labs introduces neural network chips.
1990	LSI logic chips used in consumer products.
1993	Intel introduces the Pentium processor.
1994	IBM and Motorola introduce Reduced Instruction Set Chips (RISC) for PCs, Seagate Technologies introduces the first disk drive
1995	Intel introduces the Pentium Pro processor.
1997-98	Palm introduces the first PDA.
1999	AMD introduces Athlon chips.
2001	Intel introduces Pentium 4.

Source: <http://www.sia-online.org>, Levin (1982), and <http://www.statcan.ca>

Appendix B: List of firms in my sample

There are a total of 164 semiconductor firms in my data set. As mentioned earlier, large multi-product firms that also produce semiconductor devices are excluded from this analysis.

The group of 164 firms are chosen in the following way:

1. The Compustat list (as of July 2003) of semiconductor firms is matched to the Hall, et. al (2000) patent data set. Only those firms which are present in both data sets are considered.
2. If a merger or acquisition has taken place between two firms after 1999 then those firms are counted as two different firms throughout the entire period.
3. If a firm has entered after 1999 and has subsequently merged with an existing firm (one that is present in Hall patent data-set), then that the firm-specific data for that firm are included under the name of the older firm.
4. Name changes are taken into account.
5. All \$ amounts quoted are in terms of 1983 U.S. dollar.
6. All patent data reported here are patent application data. It is possible that a firm has applied for the same patent twice under different patent application

number. However, I believe that number is very small and would have any effect on the overall analysis.

The names of all firms in the sample and their total real R&D and total number of patent applications between 1979-2002 are listed below.

Name	Total real R&D in m \$	Total patent applications
3D LABS INC LTD	12.49	5
8X8 INC	58.09	5
ACTEL CORP	189.54	164
ADVANCED MICRO DEVICES	4933.25	6024
ADVANCED PHOTONIX INC	9.42	8
ADVANCED POWER TECHNOL INC	4.98	16
AEROFLEX INC	64.62	1
ALCATEL ADS OPTRONICS	62.57	6
ALLIANCE FIBER OPTIC PRODUCT	13.74	17
ALLIANCE SEMICONDUCTOR CORP	81.41	74
ALTERA CORP	566.77	558
AMERICAN ELECTRONICS COMPONENTS	0.43	56
AMKOR TECHNOLOGY INC	61.24	130
ANADIGICS INC	124.49	26
ANALOG DEVICES	2005.55	749
APPIAN TECHNOLOGY INC	44.15	881
APPLIED MICRO CIRCUITS CORP	154.45	51
APPLIED SOLAR ENERGY CORP	10.46	9
ARTISAN COMPONENTS INC	25.17	24
ASAT HLDGS LTD	9.90	12
ASTROPOWER INC	7.56	30
ATMEL CORP	939.79	14
AUREAL INC	32.94	12
AVANTEK INC	164.91	164
AXT INC	16.62	8
BENCHMARQ MICROELECTRONICS	1.47	29
BKC SEMICONDUCTORS INC	0.56	7
BROADCOM CORP	1600.00	138
BROOKTREE CORP	88.90	81
BURR-BROWN CORP	254.33	165

Name	Total real R&D in m \$	Total patent applications
CATALYST SEMICONDUCTOR INC	31.21	18
C-CUBE SEMICONDUCTOR INC	50.64	61
CELESTICA INC	19.77	9
CHARTERED SEMICONDUCTR	174.62	511
CHIPS & TECHNOLOGIES INC	217.65	71
CONEXANT SYSTEMS INC.	1211.53	375
CREE INC	42.59	85
CYPRESS SEMICONDUCTOR CORP	1043.39	692
CYRIX CORP	73.26	82
DALLAS SEMICONDUCTOR CORP	253.31	316
DPAC TECHNOLOGIES CORP	8.20	7
E DIGITAL CORP	7.90	4
ELANTEC SEMICONDUCTOR INC	41.78	15
ELECTRONIC DESIGNS INC	8.51	1
ENERGY CONVERSION DEV	103.13	360
ESS TECHNOLOGY INC	173.54	15
E-TEK DYNAMICS INC	16.06	83
EVERGREEN SOLAR INC	5.74	15
EXAR CORP	163.97	91
FAIRCHILD SEMICONDUCTOR INTL	4871.91	2488
GALILEO TECHNOLOGY LTD	1.80	7
GATEFIELD CORP	97.09	6
GENERAL SEMICONDUCTOR INC	16.15	32
GENESIS MICROCHIP INC	61.10	25
GLOBESPANVIRATA INC	296.94	48
HEI INC	11.58	10
HI/FN INC	40.28	8
HYTEK MICROSYSTEMS INC	13.01	2
IBIS TECHNOLOGY INC	15.62	11
IMP INC	88.20	18
INFINEON TECHNLOGIES 2590.91	702	
INFORMATION STORAGE DEVICES	23.43	44
INNOVEX INC	28.62	9
INTECH INC	16.09	2
INTEGRATED CIRCUIT SYSTEMS	107.13	6
INTEGRATED DEVICE TECH INC	925.48	326
INTEGRATED SENSOR SOLUTIONS	4.79	4
INTEGRATED SILICON SOLUTION	124.86	44

Name	Total real R&D in m \$	Total patent applications
INTEL CORP	18840.00	5967
INTERSIL CORP	219.68	90
INTL RECTIFIER CORP	307.92	339
IXYS CORP	20.01	36
JETRONIC INDUSTRIES INC	2.14	3
KOPIN CORP	49.34	104
LATTICE SEMICONDUCTOR CORP	372.49	99
LEVEL ONE COMMUNICATIONS INC	91.13	40
LIGHTPATH TECH INC	15.22	20
LINEAR TECHNOLOGY CORP	325.64	170
LOGIC DEVICES INC	15.55	15
LOGICVISION INC	6.33	16
LSI LOGIC CORP	2179.61	2000
MACRONIX INTL LTD	210.51	277
MAKER COMMUNICATIONS INC	2.56	9
MARVELL TECHNOLOGY GROUP LTD	300.70	11
MAXIM INTEGRATED PRODUCTS	638.93	180
MELTRONIX INC	8.00	5
MEMC ELECTRONIC MATRIALS INC	302.70	173
METALINK LTD	6.78	3
MICREL INC	139.67	55
MICRO LINEAR CORP	68.92	56
MICROCHIP TECHNOLOGY INC	299.18	171
MICRON TECHNOLOGY INC	1758.31	7326
MICROSEMI CORP	48.69	8
MICROTUNE INC	46.73	15
MONOLITHIC MEMORIES INC	112.11	38
MONOLITHIC SYS TECHNOLOGIES	6.79	24
NEOMAGIC CORP	102.13	59
NEW FOCUS INC	97.54	51
NEXGEN INC	10.07	10
NVIDIA CORP	325.65	58
O2MICRO INTERNATIONAL LTD	18.68	3
OMNIVISION TECHNOLOGIES INC	17.41	24
ON SEMICONDUCTOR CORP	139.23	2
ON TRACK INNOVATIONS LTD	5.35	5
OPTEK TECHNOLOGY INC	6.30	5
OPTI INC	48.65	38

Name	Total real R&D in m \$	Total patent applications
OPTICAL COMMUNICATION PRODS	6.06	2
ORBIT SEMICONDUCTOR INC	5.11	1
PANDA PROJECT INC	14.08	16
PARADIGM TECHNOLOGY INC	9.13	17
PERICOM SEMICONDUCTOR CORP	26.71	45
PLX TECHNOLOGY INC	44.74	4
PMC-SIERRA INC	534.25	72
POWER INTEGRATIONS INC	37.78	56
QLOGIC CORP	188.32	17
QUALITY SEMICONDUCTOR INC	23.99	13
QUICKLOGIC CORP	25.16	78
RAMTRON INTERNATIONAL CORP	92.17	110
RF MICRO DEVICES INC	177.61	23
RIPLEY CO INC	1.72	5
ROSS TECHNOLOGY INC	29.80	5
SAGE INC	4.73	3
SDL INC	40.78	149
SEMICON INC	4.79	3
SEMTECH CORP	92.26	25
SIGMA DESIGNS INC	59.57	21
SIGMATRON NOVA INC	0.62	4
SILICON IMAGE INC	65.38	24
SILICON LABORATORIES INC	53.45	54
SILICON STORAGE TECHNOLOGY	116.42	49
SILICON SYSTEMS INC	40.18	89
SILICONIX INC	263.16	217
SILTEC CORP	17.61	8
SIMTEK CORP	19.85	13
SIPEX CORP	41.89	15
SKYWORKS SOLUTIONS INC	243.63	53
SMART MODULAR TECHNOLGS INC	18.03	1
SOLITRON DEVICES INC	13.69	7
STANDARD MICROSYSTEMS CORP	272.06	70
STMICROELECTRONICS N V	4065.83	3
STRATOS LIGHTWAVE INC	28.65	177
SUPERTEX INC	66.05	20
TAIWAN SEMICONDUCTOR	416.71	2130
TELCOM SEMICONDUCTOR INC	15.37	18

Name	Total real R&D in m \$	Total patent applications
TEXAS INSTRUMENTS INC	12232.61	9218
THREE-FIVE SYSTEMS INC	46.45	13
TOWER SEMICONDUCTOR LTD	31.20	39
TRANSMETA CORP	116.89	14
TRANSTECTOR SYSTEMS INC	2.58	2
TRANSWITCH CORP	81.27	39
TRIDENT MICROSYSTEMS INC	121.85	5
TRIPATH TECHNOLOGY INC	32.86	20
TRIQUINT SEMICONDUCTOR INC	147.98	54
UNITRODE CORP	135.08	70
UNIVERSAL DISPLAY CORP	33.35	6
UTD MICROELECTRONICS	341.75	2253
VITESSE SEMICONDUCTOR CORP	354.74	32
VLSI TECHNOLOGY INC	522.54	1108
WHITE ELECTRIC DESIGNS CORP	23.96	2
XICOR INC	208.87	40
XILINX INC	788.51	738
ZARLINK SEMICONDUCTOR INC	413.60	225
ZILOG INC	190.61	137
ZORAN CORP	48.89	24

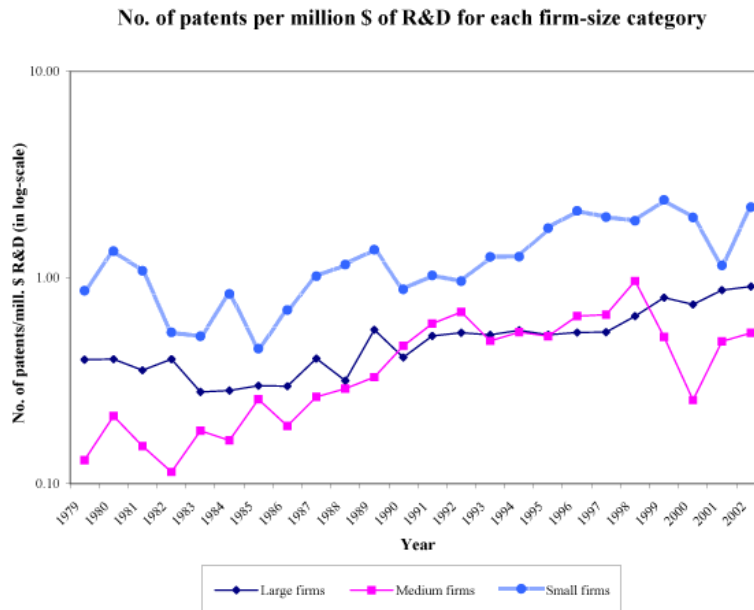


Figure 19: No. of patents per R&D \$ for different firm-size categories

Appendix C: Patenting and R&D in different firm size category according to sales

In this section firm sizes are determined by looking at their nominal sales in the year 2000. Firms with sales greater than 700 million dollars are considered large; firms with sales between 100-700 million dollars are considered medium and firms with sales less than 100 million are considered small.

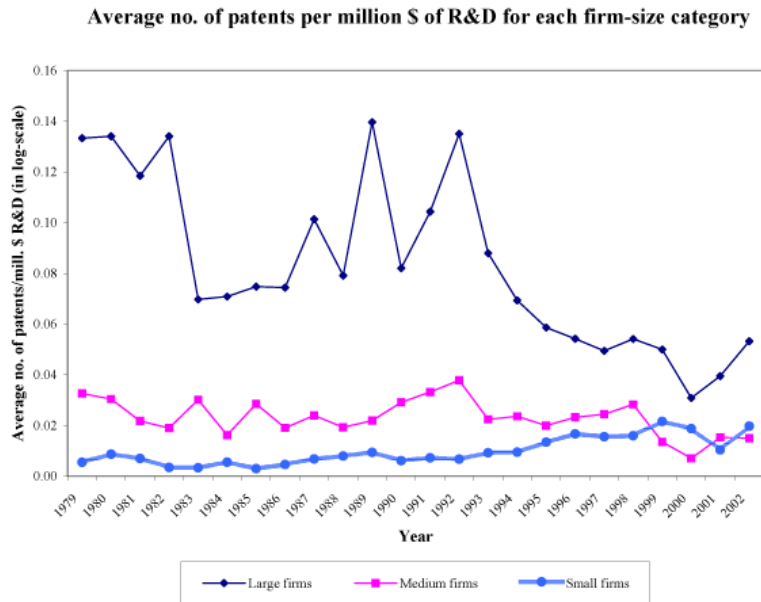


Figure 20: Average no. of patents per R&D \$ for different firm-size categories

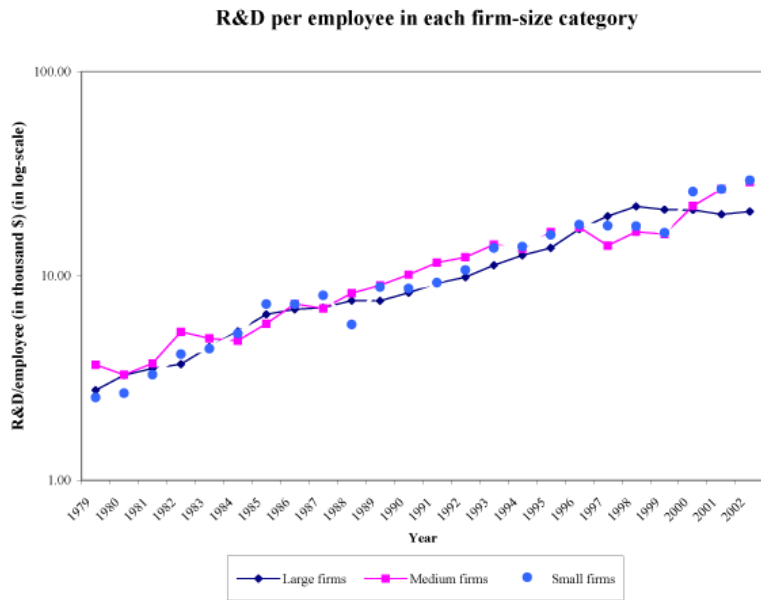


Figure 21: R&D per employee for different firm-size categories

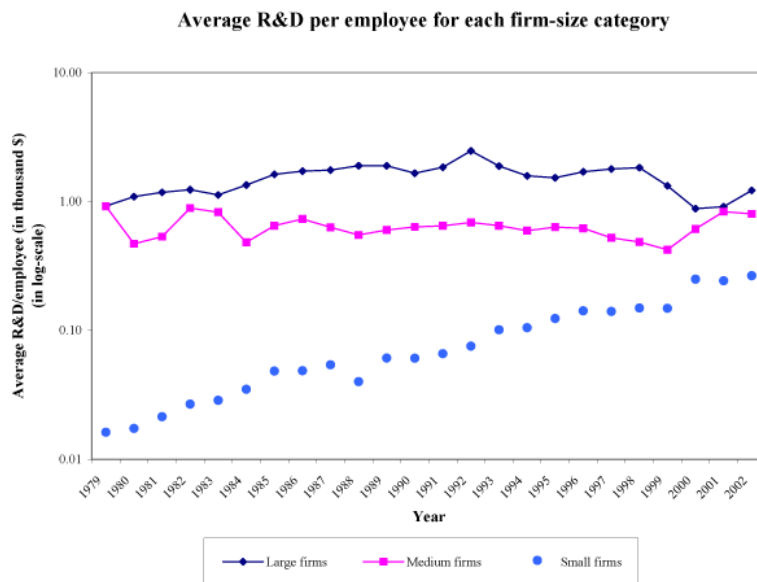


Figure 22: Average R&D per employee for different firm-size categories