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The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 1979–1995

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We examine the patenting behavior of firms in an industry characterized by rapid technological change and cumulative innovation. Recent survey evidence suggests that semiconductor firms do not rely heavily on patents to appropriate returns to R&D. Yet the propensity of semiconductor firms to patent has risen dramatically since the mid-1980s. We explore this apparent paradox by conducting interviews with industry representatives and analyzing the patenting behavior of 95 U.S. semiconductor firms during 1979–1995. The results suggest that the 1980s strengthening of U.S. patent rights spawned "patent portfolio races" among capital-intensive firms, but it also facilitated entry by specialized design firms.

1. Introduction

■ In the early 1980s, important changes in the U.S. legal environment ushered in an era characterized by strong patent rights. Most notable among these changes was the 1982 formation of a centralized appellate court, the Court of Appeals for the Federal Circuit (CAFC). Although the CAFC is widely credited with unifying and strengthening

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the judicial treatment of patent rights in the United States, the effects of the "pro-patent" court on the innovative activities of firms remain unclear. For example, survey evidence suggests that firms in most industries have *not* increased their reliance on patents for appropriating the returns to R&D over the decade of the 1980s (Cohen, Nelson, and Walsh, 2000). Yet this period coincides with an unprecedented surge in patenting in the United States unaccounted for by increases in R&D spending alone (Kortum and Lerner, 1998). If firms in most industries do not rely heavily on patents to profit from innovation, then why are they patenting so aggressively?

This article revisits this "patent paradox" in the semiconductor industry, where the gap between the relative ineffectiveness of patents (as reported in surveys) and their widespread use is particularly striking. In two surveys on appropriability conducted in 1983 and 1994 (the "Yale" and "Carnegie Mellon" surveys, respectively), R&D managers in semiconductors consistently reported that patents were among the *least* effective mechanisms for appropriating returns to R&D investments (Levin et al., 1987; Cohen, Nelson, and Walsh, 2000). Driven by a rapid pace of technological change and short product life cycles, semiconductor firms tend to rely more heavily on lead time, secrecy, and manufacturing or design capabilities than patents to recoup investments in R&D. Nonetheless, the number of semiconductor-related patents issued in the United States has risen sharply since the early 1980s, exceeding the overall increase examined by Kortum and Lerner (1998).[1] Even more important, the *propensity* of semiconductor firms to patent has also risen during this period. As shown in Figure 1, we find that patenting per million real R&D dollars in the semiconductor industry doubled between 1982 and 1992, from about .3 to .6.[2] During the same period, the patent yield for manufacturing as a whole was fairly stagnant and that for pharmaceuticals declined.[3]

The semiconductor industry also provides an excellent setting within which to examine the effects of stronger patent rights on firms engaged in rapidly advancing, "cumulative" technologies. Much like multimedia or computer firms, semiconductor firms often require access to a "thicket" of intellectual property rights in order to advance the technology or to legally produce or sell their products. Given the rapid pace of technological change in this industry, however, any new product or process is likely to overlap with technologies previously or simultaneously developed by external parties (Grindley and Teece, 1997). Despite significant advancements in the theoretical literature on the importance of strong patent rights for inducing investments in R&D when innovation is cumulative (e.g., Scotchmer, 1996; O'Donoghue, Scotchmer, and Thisse, 1998), there remains little systematic evidence on how a shift toward stronger patent rights affects the innovative activities of firms in the context of rapidly changing, cumulative technologies.[4] Our article casts new empirical light on this issue by examining the patenting behavior of semiconductor firms during a period that spans the pro-patent shift in the U.S. legal environment.

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[1] The number of U.S. patents issued in a narrowly defined set of semiconductor patent classes more than doubled between 1981 and 1984, while the number of U.S. patents issued in all patent classes rose by only 50% during this period (USPTO, 1995).

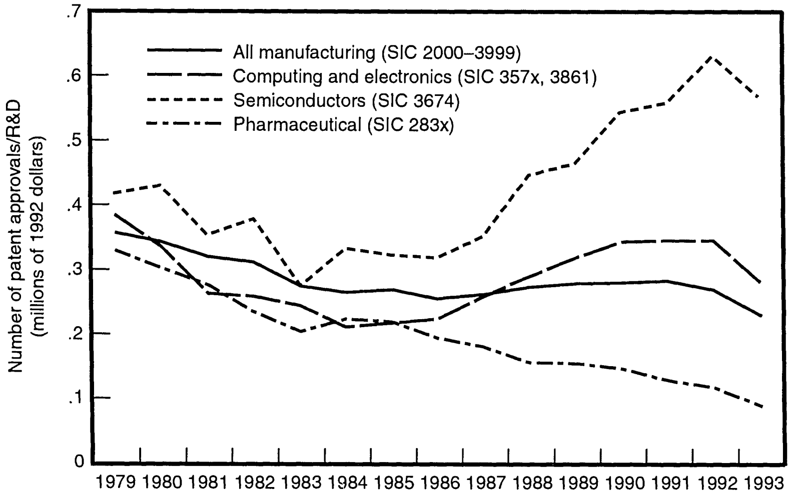
[2] We define successful patent applications as applications that eventually result in an issued U.S. patent. To avoid noise introduced by outliers with small R&D programs, Figure 1 plots total patents per total R&D spending in the sector, rather than the average of the patent-R&D ratios for each firm.

[3] The patent yield for semiconductors is based on the universe of 110 publicly traded firms in SIC 3674 (see Section 4). Trends are reported through 1993 to avoid an artificial truncation due to the lag between application and issuance dates.

[4] The most extensive treatment of these issues (Merges and Nelson, 1990) relies on historical records to trace the effects of conferring broad patent rights to inventors engaged in so-called cumulative systems technologies, including electronics, aircraft, or automobiles. See Mazzoleni and Nelson (1998) for a thoughtful discussion of the findings.

FIGURE 1

PROPENSITY TO PATENT: U.S. MANUFACTURING INDUSTRIES



To illuminate the factors underpinning the surge in patenting in this industry and the effects, if any, of stronger U.S. patent rights on the innovative activities of semiconductor firms, we employ a combination of qualitative and quantitative research methods. First, we conducted interviews with intellectual property managers and executives from several U.S. semiconductor firms—including manufacturers and specialized design firms. Earlier studies have explored the motives for patenting in this industry (e.g., Tilton, 1971; Taylor and Silberston, 1973; Levin, 1982; von Hippel, 1988). We sought additional insights on whether the increased patenting per R&D dollar we find in this industry appears to be related to the strengthening of U.S. patent rights in the 1980s or whether it seems to be driven by unrelated technological or managerial factors (an important alternative hypothesis). These interviews also enable us to investigate the use of patents by semiconductor design firms, which specialize in chip design and contract out the manufacture of their products to other firms. Many of these firms entered the industry during the period associated with strong patent rights, but the importance of patents to these firms was unclear.

Our quantitative analysis is based on a larger sample of approximately 100 publicly traded U.S. firms whose principal line of business is semiconductors and related devices (SIC3674) and whose R&D expenditures are therefore primarily directed toward semiconductor-related areas. After compiling a detailed database of these firms' patent portfolios from 1975 to 1998, we match these data with financial variables from Compustat (e.g., R&D and sales) that are known determinants of patenting in general and that capture additional variables identified in our interviews. This methodology enables us to advance upon existing studies by constructing reliable estimates of the patent propensities of individual firms during this twenty-year period while keeping the broad technological area constant across firms.[5] Thus, we are able to determine whether the upsurge in patenting simply represents changes in the mix of firms in the industry over time (i.e., the effects of entry and exit), changes in the economic behavior of firms, or

[5] In contrast, Kortum and Lerner (1998) use aggregate R&D and patent data. Using a different approach, Cohen, Nelson, and Walsh (2000) construct a useful firm-level estimate of "patent propensity" using 1994 survey data, but are unable to track changes in this important variable over time.

both. An unfortunate weakness of this approach is the exclusion from our analysis of large U.S. "systems" manufacturers (e.g., IBM, AT&T, or Motorola) and non-U.S. firms (e.g., Toshiba, Samsung, or Siemens) that are important patent owners and users of semiconductor technologies. Because corporate R&D spending is reported for the entire portfolio of a firm's R&D activities, it is not possible to isolate the share of R&D expenditures directed toward semiconductor technologies for these diversified firms.

Our central hypothesis is that the surge in patenting by semiconductor firms is causally related to the pro-patent shift in the U.S. legal environment in the 1980s. We distinguish, however, between two potentially divergent effects on firms within this sector. First, we examine whether firms most vulnerable to "holdup" in the new patent regime (i.e., firms with large sunk costs in complex manufacturing facilities) respond strategically to the institutional shift by expanding their own portfolios of patents with which to trade. We label this our "strategic response" hypothesis, which we test by examining the patenting behavior of large-scale manufacturers and whether it has changed in the period of strong U.S. patent rights. We then examine whether the strengthening of U.S. patent rights facilitated vertical specialization within the industry and led to the emergence of "technology specialists" (Merges, 1998; Arora, 1995). We test this "specialization" hypothesis by assessing whether the surge in patent propensities in this industry under the new patent regime is explained by the emergence of more patent-intensive design firms.

Several important findings emerge from our research. First, estimating firm-level patenting behavior during 1979–1995 reveals that the upsurge in patenting by U.S. semiconductor firms is indeed quite remarkable. Controlling for the changes in the mix of firms leaves the upward trend shown in Figure 1 essentially unchanged. Second, our qualitative and quantitative evidence suggests that the pro-patent shift contributed to intensified patenting in this industry, but in ways not examined systematically in previous studies. On the one hand, we find that large-scale manufacturers have invested far more aggressively in patents during the period associated with strong U.S. patent rights, even controlling for other known determinants of patenting (consistent with our strategic response hypothesis). Instead of being driven by a desire to win strong legal rights to a standalone technological prize, these firms appear to be engaged in "patent portfolio races" aimed at reducing concerns about being held up by external patent owners and at negotiating access to external technologies on more favorable terms. On the other hand, we find that firms entering the industry since 1982 patent more intensively than pre-1982 entrants. This is especially true of specialized design firms founded after 1982; in fact, we see a considerable increase in entry by this type of firm (consistent with our specialization hypothesis). Our interviews suggest that stronger patent rights are especially critical to these firms in attracting venture capital funds and securing proprietary rights in niche product markets.

Although these results highlight the multifaceted role that patents can play among firms even within the same broad technological area, we find that the primary reason for intensified patenting among our sample of semiconductor firms is more aggressive patenting by capital-intensive firms (strategic response). The results of our econometric analysis corroborate views commonly expressed by industry representatives that the 1980s pro-patent shift in the U.S. legal environment altered these firms' incentives to patent. Nonetheless, we contrast these findings with those implied by two competing views. First, the surge in U.S. patenting could be attributed to more aggressive patenting by firms with large patent portfolios in the period preceding the CAFC's formation, as posed by Kortum and Lerner's (1998) "regulatory capture" hypothesis in the context of their cross-industry study. We too find little evidence that the even more dramatic surge in patenting by semiconductor firms is driven by scale effects alone or by more aggressive post-1982 patenting by Texas Instruments, the one firm in our sample with large absolute levels of patents in the pre-1982 period. Second, it is possible that the increased patenting per R&D dollar that we observe in this industry is driven by unrelated technological or managerial changes that have simply improved the productivity of the research process. We investigate this "unrelated R&D productivity" hypothesis, which Kortum and Lerner found most consistent with the patterns revealed in their aggregate data, at length in our interviews and empirically test it in the context of the semiconductor industry in Section 5. We too find evidence of managerial improvements during the period of our study, but primarily in how semiconductor firms manage their intellectual property rather than in the management of their R&D labs per se.

The article is organized as follows. In Section 2 we discuss the shift toward stronger U.S. patent rights during the 1980s and highlight recent empirical studies that have examined its effects on the patent propensities of firms. In Section 3 we focus more narrowly on the role of patents in the semiconductor industry and present the results of our interviews. Section 4 contains the econometric analysis, describes the data and methods we use, and presents our results. In Section 5 we examine more closely the alternative view that the intensified patenting in this industry stems from factors unrelated to the strengthening of U.S. patent rights. Brief concluding remarks follow.

2. The institutional change and its anticipated effects

■ The patent system has long been recognized as an important policy instrument used to promote innovation and technological progress. Two fundamental mechanisms underpin the patent system. First, an inventor discloses to the public a "novel," "useful," and "nonobvious" invention. In return, the inventor receives the right to exclude others from using that patented invention for a fixed period of time (now 20 years from the date of patent application in the United States). The rules of the patent game may differ from country to country (e.g., whether rights are assigned to the first inventor or the first to file the patent application), but the underlying principle remains the same. By providing exclusionary rights for some period of time and a more conducive environment in which to recoup R&D investments, the patent system aims to encourage inventors to direct more of their resources toward R&D than would otherwise be the case. At the same time, detailed information about the invention is disclosed to the public when the patent application is published.

□ **The shift toward stronger U.S. patent rights.** In the early 1980s, important changes in the U.S. legal environment effectively strengthened the rights conferred to holders of U.S. patents. In particular, the 1982 creation of the Court of Appeals for the Federal Circuit, a centralized appellate court, not only unified the judicial treatment of patent rights in the United States, but transformed the legal environment from one that was generally skeptical of patents to one that promoted the broad, exclusive rights of patent owners (Adelman, 1987; Merges, 1997). For example, the new court endorsed the broad exclusionary rights of patent owners through its interpretation of patent scope and made it more difficult to challenge a patent's validity by raising evidentiary standards (Merges, 1997). The court was also more willing to grant preliminary injunctions to patentees during infringement suits (Lanjouw and Lerner, 1996), sustain large damage awards (Merges, 1997; Kortum and Lerner, 1998), and issue rulings that have collectively been construed as "pro-patent." Plaintiff success rates in patent infringement suits also increased substantially during this period (Lerner, 1995).

Although the importance of the CAFC in strengthening U.S. patent rights has been widely noted, the actual effects of the pro-patent shift on the innovative activities of firms remain unclear (see Jaffe, 2000). To the extent that stronger patent rights enable firms to recoup more of their R&D dollars, stronger patent rights should increase incentives to invest in R&D.[6] But there is no *a priori* reason to expect that these increased R&D dollars should yield proportionally more patents. Unless other changes in the content or management of R&D occurs (such as a shift toward more "applied," patentable activities or improvements in research methods that speed or ease the inventive process), stronger patent rights should not necessarily generate an increase in the numbers of patents generated per R&D dollar.[7]

In light of the above discussion, it is interesting to note that previous empirical studies have failed to find evidence that the strengthening of U.S. patent rights during the 1980s stimulated industrial spending in R&D. Kortum and Lerner (1998) demonstrate that the upswing in U.S. industrial R&D spending predates 1982. Moreover, they find that the intensity of research effort leveled off in the late 1980s and early 1990s, whereas patenting rates continued to climb. In another study, Bessen and Maskin (2000) show that real R&D intensity in information technology related industries (including semiconductors, telecommunications, and computers) has fallen steadily since around 1982, providing little evidence that the strengthening of patent rights stimulated R&D spending by firms in these industries. Similar evidence exists for the firms in our sample: incumbent firms (those who entered the industry before 1983) show a slight decline in their R&D intensity, whereas entrants (half of whom are design firms, which specialize in R&D) show some increasing R&D intensities at first and then a decline. Thus, the surprising first-order effect of the pro-patent shift in many industries seems to be an increase in patenting rather than an increase in R&D spending per se. Due to the omission of other factors that may have influenced firm-level R&D spending during this period, however, one should be cautious about drawing strong conclusions from these aggregate time series data alone.

□ **Exploring the link between the "pro-patent" shift and intensified U.S. patenting.** The study by Kortum and Lerner (1998) previously cited examines these somewhat puzzling empirical trends in more detail to determine whether, in fact, the 1980s strengthening of U.S. patent rights led to the explosion in U.S. patenting or whether the two are simultaneous but unrelated events. Their central hypothesis, like ours, is that the surge in patenting is related to this strengthening of U.S. patent rights associated with the 1982 formation of the CAFC (their "friendly court" hypothesis). The authors test this hypothesis by examining evidence on worldwide patenting: if U.S. patents become more valuable because of the pro-patent shift, then the United States should become a more important "destination" country for international patent filers following the CAFC's formation. They find little support for this hypothesis in the aggregate data and reject the view that the overall surge in U.S. patenting is linked to the strengthening of U.S. patent rights in the early 1980s. Kortum and Lerner also find little evidence for a variant of their friendly court hypothesis, which suggests that incumbents with large patent portfolios in the pre-CAFC period account for the subsequent increase in

[6] A traditional issue in the patent-design literature is whether strong patents lead to socially wasteful "patent races" and *overinvestment* in R&D. More recent studies suggest that the R&D incentives provided by strong patents are especially important when innovation is cumulative (e.g., Scotchmer, 1991, 1996; Green and Scotchmer, 1995; O'Donoghue, 1998).

[7] Appendix B of an earlier, expanded version of this article includes a simple model that shows this result. The article is available at the following Web site: *http://jonescenter.wharton.upenn.edu/papers/2000.htm.*

patenting (their "regulatory capture" hypothesis). Through a process of elimination, Kortum and Lerner conclude that the surge in U.S. patenting over the past two decades appears to stem from a broad increase in R&D productivity. In this view, the historically unprecedented rise in U.S. patenting rates since the 1980s is in fact unrelated to the simultaneous changes in the U.S. legal environment. Instead, it appears to be driven by more general improvements in the management or automation of the innovation process.

Kortum and Lerner (1998) highlight an important phenomenon, but their use of aggregate rather than firm-level data may have led them to dismiss too quickly the potential effects of the pro-patent shift, at least in the context of the semiconductor industry, where the surge in patenting (relative to firm-level R&D spending) is most dramatic. In semiconductors, we would modify the analysis of Kortum and Lerner in several ways. First, it was clear from talking with industry representatives that regulatory capture (implying a more aggressive use of intellectual property rights by large firms with deep pockets) could induce other firms to patent more aggressively in order to improve their negotiating position with these large owners of intellectual property. If this is true, regulatory capture does not necessarily imply that large patent owners will have a greater relative incentive to patent than firms most subject to "holdup" (either by large patent owners or a more diverse set of entities) in the era of strong patent rights. We examine this strategic response hypothesis below.

Second, we interpret changes in the "management of R&D" more broadly. Even with few changes in the strategy and goals of their R&D programs, it was clear from our conversations that many manufacturers had decided to "harvest" more patents from their R&D, both as a defensive strategy (e.g., "to ensure the freedom to design and manufacture") and to assist them in winning favorable terms in cross-licensing negotiations with other firms in the industry. The results of the 1994 Carnegie Mellon Survey of Industrial R&D in the United States (Cohen, Nelson, and Walsh, 2000) highlight the importance of these broader motives for patenting among firms engaged in cumulative, "complex" technologies, including but not limited to semiconductors.[8] This finding has important implications, not only on the broader use of patents by firms in many high-technology industries, but on unravelling the potential effects of strengthening patents rights in areas where the value of a single patent is inherently tied to that of other patented and unpatented technologies. We explore the implications of these issues at length in our interviews and empirically in Section 5.

Finally, the pro-patent policies put in place by the CAFC may have facilitated entry by firms specializing in R&D-intensive inputs even within existing industries (Merges, 1998; Arora and Fosfuri, 1998). Indeed, the period associated with strong U.S. patent rights has witnessed significant entry into the semiconductor industry by design, or "fabless," firms that specialize in innovative products but contract out the manufacture of their products to owners of wafer fabrication facilities. Division of labor in this industry was aided by the widespread adoption in the 1980s of the metal-oxide silicon (MOS) manufacturing process, which provided a more standardized interface between chip design and the wafer fabrication process (Macher, Mowery, and Hodges, 1998). To the extent that product innovations are generally better suited to protection with patents (Levin et al., 1987), however, we might expect specialized design firms to exhibit a relatively high propensity to patent based on their R&D spending. Moreover, as "technology specialists," these firms may rely more heavily on patents to

[8] Other "complex" industrial settings included computers, electrical equipment, instruments, transportation, and machinery (Cohen, Nelson, and Walsh, 2000).

appropriate returns to innovation than firms owning complementary assets in manufacturing (Teece, 1986). It is possible therefore that the increased propensity to patent we observe in this industry is driven by the emergence of these patent-intensive firms. With this in mind, we explore the importance of patents to design firms in our interviews and return to this specialization hypothesis in our econometric analysis.

3. Field interviews

■ To illuminate the factors that have influenced patenting in the semiconductor industry and the effects, if any, of the 1980s shift toward stronger U.S. patent rights on the innovative activities of different types of firms, we met with intellectual property managers and executives from seven semiconductor firms, including four manufacturers and three design firms. We conducted these interviews (which included structured questions and a follow-up survey) between April 1998 and November 1998.

In each case, we asked to meet with someone with direct responsibility for formulating and implementing the firm's patent strategy. Identifying relevant decision makers was straightforward for small firms: we typically met with someone with a legal/engineering background who was in charge of the firm's patenting activities; in one case, we met with the firm's CEO. For larger firms, we typically met with two or more persons, including in-house patent or corporate attorneys, patent licensing executives, or R&D lab managers. To gain additional views on whether the firms in our sample are representative of industrywide or cross-industry trends, we also met with attorneys actively involved in negotiating patent-related transactions on behalf of a broad set of firms, including ones in the semiconductor industry. The interview sample includes a range of firms in terms of size and patent intensity. Only one firm, Texas Instruments, held a large patent portfolio (both in absolute terms and relative to its R&D spending) prior to the shift in U.S. patent policies. See Ziedonis (2000) for more information on these interviews.

Without exception, interviewees emphasized that the stronger patent rights ushered in by the CAFC reshaped the incentives to obtain U.S. patents in this industry. But the implications of the pro-patent shift appeared to differ among the types of firms in the interview sample, depending on the size and strength of a firm's patent portfolio in the early 1980s and the extent to which other patent owners could credibly threaten to exclude the firm from using critical technologies. Despite the small number of firms in the interview sample, questions about the perceived effects of the early-1980s shift in U.S. patent policies generated a rich set of findings (see Ziedonis, 2000). Here, we focus on differences between manufacturing firms and design firms that inform our econometric analysis below.

□ **Large-scale manufacturers: the increased value of patents as bargaining chips.** Several large-scale manufacturers in our sample were visibly "ramping up" their patent portfolios and "harvesting" latent inventions to add to their stock of patents. For example, one firm had shifted from owning a total of 30 patents (in 1990) to filing over 300 patent applications in one year—with an internal goal to "own 1,000 patents by the year 2000." Another manufacturer had instituted an even more ambitious "1,000 by 2000" patent goal while maintaining a relatively stable R&D budget. In this case, the firm had embarked on an explicit campaign to file 1,000 patent applications in a single year by the year 2000. In line with this goal, the number of annual patent applications filed by the firm rose from around 100 in 1993 to over 650 by 1996. The increased volume of patent filings appeared to reflect a deeper reach into an existing pool of inventions rather than a shift in R&D activities per se. As one interviewee noted, there were "a lot of patentable inventions sitting around," but the firm had simply "not taken the time and incurred the cost" to patent, or "harvest," these inventions in the past.

Two events, both related to the more favorable judicial treatment of U.S. patent rights, were frequently mentioned as having played a pivotal role in reshaping the patent strategies of these firms. First, interviewees emphasized the important "demonstration effect" of Polaroid's successful patent infringement suit against Kodak; in 1986, Polaroid was awarded almost $1 billion in damages and Kodak was barred from competing in the instant-film camera business (see Barton and Parapatt, 1998). The large penalties imposed in this case and the realization that U.S. courts were willing to take an aggressive stance against infringement by halting—either temporarily or permanently—production utilizing infringed technologies appear to have heightened concerns among executives in large-scale manufacturing firms about the potential costs and risks associated with patent infringement. According to some interviewees, until the Kodak-Polaroid case, their firms generally expected to pay royalties on past use of the property covered by an infringed patent (a reasonable risk and slightly less expensive in an expected-value sense than paying royalties from the beginning); in contrast, after the Kodak-Polaroid case, firms perceived a higher likelihood that "payment" could entail being shut down with an injunction. As one interviewee noted, "a preliminary injunction would be detrimental to a firm if it means shutting down a high-volume manufacturing facility; loss of one week's production alone can cost millions of dollars." The licensing director of another firm agreed that the threat of injunction is a powerful lever against manufacturers—especially if the cost associated with halting production is high and firms have already integrated the technologies into their production processes. The more costly and difficult it is for the infringing party to "invent around" the patented technology, the more favorable the negotiating position of the party who owns the legal "right to exclude."

A second widely cited reason for intensified patenting in the industry was referred to by some as a "Texas Instruments" effect. During 1985–1986, Texas Instruments successfully asserted its patents in court for a range of inventions pertaining to integrated circuits (e.g., the "Kilby patent" on the basic design of the integrated circuit) and manufacturing methods (e.g., the method for encapsulating chips or transporting wafers from one manufacturing platform to another). Although the original suits were against non-U.S. firms, TI's successful enforcement of its patents enabled the firm to charge higher royalty rates to other firms in the industry. Indeed, interviewees were well aware of the strategies that Texas Instruments had put in place to manage—and profit from—its patent portfolio; representatives from several firms plan to adopt a similarly aggressive licensing strategy once their portfolios grow larger. Others noted that AT&T, IBM, and Motorola began asserting their patent rights more aggressively around the same time in order to increase licensing revenues based on their large portfolios of semiconductor-related patents. According to several industry representatives, these large patent owners not only increased royalty rates for "rights to use" their patents, but increasingly sought royalty-bearing licenses from smaller firms.

Citing these effects, interviewees from large-scale manufacturing firms typically noted that patents had become far more important to their firms during the pro-patent environment to use as bargaining chips in negotiations with other patent owners. Some noted that the semiconductor industry has historically been characterized by broad cross-licenses of patent rights among manufacturers. To a large extent, this is still the case (see Grindley and Teece, 1997). Nonetheless, a firm lacking a strong patent portfolio of its own with which to negotiate licensing or cross-licensing agreements could face a more rapid erosion of profits in an era when the costs and risks associated with infringement had increased. For example, one industry executive estimates that "a new manufacturer would need to spend $100–$200 million of revenues to license what are now considered basic manufacturing principles but which do not transfer any currently useful technologies" (as quoted in Headley, 1998).

Two factors emerged from these interviews that may exacerbate these general "holdup" concerns among large-scale manufacturers in the semiconductor industry. First, several firms were investing in more expensive facilities that were becoming obsolete more quickly. For example, in the early 1980s, a state-of-the-art wafer fabrication facility (fab) cost about $100 million and had an expected lifespan of 10 years. By the mid-1990s, however, the cost had risen to over $1 billion for a new fab, while the useful life of the capital investment had been reduced to little more than 5 years (ICE, 1995). Semiconductor manufacturing is also notoriously complex, integrating an array of process and product technologies that cover aspects of the circuitry design, materials used to achieve a certain outcome, and methods used in the wafer fabrication process (see Ham, Linden and Appleyard, 1998; Grindley and Teece, 1997). As several industry representatives pointed out, a given semiconductor product (say, a new memory or logic device) will often embody hundreds if not thousands of "potentially patentable" technologies that could be owned by suppliers, manufacturers in other industries, rivals, design firms, or independent inventors. With the strengthening of U.S. patent rights, the expected benefits of amassing portfolios of "legal rights to exclude" (for offensive and defensive reasons) began to outweigh their costs.[9]

□ **Design firms: securing rights in niche product markets?** The "bargaining chip" role of patents was less apparent in our interviews with firms specializing in the design of semiconductor products. Two highly profitable design firms in our interview sample had established sophisticated in-house patent committees and were patenting aggressively in their core product lines. Unlike manufacturers, these firms appeared to be driven by a desire to secure strong, "bulletproof" proprietary rights to technologies in niche product markets. Although one firm was starting to patent for defensive reasons (i.e., in anticipation of future requests for royalty-bearing licenses), patents were mainly used to improve these firms' competitive position vis-à-vis direct market rivals. The small number of design firms in our interview sample negotiated surprisingly few licensing agreements involving the sale of rights to their patented technologies or the acquisition of such rights from others. Put differently, patent rights appeared to be more important to these firms for "horizontal" reasons (to gain market share from rival firms) than for "vertical" reasons, such as exchanging know-how or technology with suppliers of manufacturing services or customers (Arora and Fosfuri, 1998; Arora, 1995). The primary vertical role of patenting for this small group of firms appeared to be in securing capital from private investors in the startup phase. Similarly, when asked to consider the effects of an extreme hypothetical scenario in which the U.S. patent system was abolished, representatives from both design firms and manufacturers typically raised concerns about the chilling effect on entry by these specialized firms.

The overall picture that emerged from both sets of interviews was the importance of patents as an imperfect but quantifiable measure of technology that enabled technology-based trades to be made in external markets, both in financial markets (venture capital) and with suppliers and owners of complementary technologies. Although the

[9] According to several interviewees, patents are so difficult to value that some licensing negotiations are conducted using patent *counts* as the unit of currency. Clearly, to the extent that this practice is widespread, firms have incentives to apply for patents on minor innovations with no other intrinsic value.

sample underpinning these interviews is not necessarily representative of the industry as a whole, the general insights suggest that the shift in patent policies in the early 1980s increased the incentives of firms in this industry to patent (with notable exceptions; see Ziedonis (2000)), albeit for reasons that differ among types of firms.

4. Empirical analysis

■ Conclusions from our interviews with participants in this industry are necessarily limited by the size of the sample and the retrospective nature of some of the questions. In this section we examine the patenting behavior of a larger sample of semiconductor firms over a period that spans the pro-patent shift in the U.S. legal environment in order to ascertain the generality of our earlier findings. Our approach here is econometric rather than qualitative, and we rely primarily on data that are publicly available (accounting data including R&D spending, and patent grant data). In general, our results using the large sample of firms corroborate the main findings from our field research. Before describing the results of our analyses, we describe our data construction and the broad features of our data.

□ **Sample selection and data.** The econometric part of this study is based on the universe of 110 publicly traded U.S.-owned firms whose principal line of business is in SIC 3674 (semiconductors and related devices) and that have data on Compustat between 1975 and 1996. To this universe we added a small number of publicly traded U.S. semiconductor firms that were assigned to other 4-digit classes.[10] Because the purpose of this study is to examine changes in the patenting propensities of semiconductor firms over time, we needed reliable indicators for both the patented output of semiconductor firms and the semiconductor-related R&D investments (inputs) of these firms. As discussed earlier, corporate R&D spending is reported for a firm's entire portfolio of research activities, so we included only firms whose R&D investments are primarily directed toward technologies aimed at semiconductor-related products.

For this analysis we restricted the sample to 1979 (the first year in which there are more than 20 firms) through 1995 (because of the truncation of the patent data after that date due to lags in the granting of patents). We also dropped partially-owned subsidiaries and excluded firms that had less than three years of complete data. The final sample contains 95 firms in an unbalanced panel that has 946 firm-year observations. The omitted firms were primarily small post-1994 startups for which we had inadequate data.

A major challenge in any study that examines the patenting activities of firms over time is identifying which patents are assigned to individual firms in a given year. Firms patent under a variety of names (their own and those of their subsidiaries), and the U.S. Patent and Trademark Office does not keep a consistent identifier for the same patenting entity from year to year. To construct the entity-level patent portfolios of the firms in our study, we first retrieved the patent portfolios of the firms included in the NBER-Case Western patent database of 3,000 manufacturing firms (described in Trajtenberg, Jaffe, and Hall, 2000). We supplemented these data with updated entity-level portfolios for the firms in our study by identifying name changes, subsidiaries, and mergers and acquisitions from a variety of sources.[11] These searches generated a total

[10] Dedicated U.S. semiconductor firms that fell in 4-digit classes other than SIC 3674 were identified using ICE Status Reports (1976–1998). The names of firms in the estimation sample are listed in Table A:1 of an earlier version of our article (see footnote 7).

[11] We identified name changes, subsidiaries, and merger and acquisition information from a variety of sources, including Lexis/Nexis business directories, 10-K filings, and the Directory of Corporate Affiliations. The online version of our article describes the sources we used in more detail (see footnote 7).

of 17,228 patents issued to these 95 firms that were applied for between 1979 and 1995, for an average of 241 total patents per firm. In contrast, 519 patents were issued to the omitted firms, an average of 17 total patents per firm.

The entity-level patent portfolios were combined with each firm's detailed balance sheet and income statement data from Compustat. The resulting "matched" database combines, for all 95 firms, the front page patent information for patents issued during 1979–1995 (e.g., the patent number and class, the date the patent was applied for and issued) with information contained in Compustat (e.g., annual R&D spending, capital expenditures, number of employees, and sales). Finally, we used business directories and industry sources to identify the founding date of each firm, which may precede the date for which we have data by many years, and to determine whether the firm owns and operates its own fab (manufacturer) or specializes in product design alone (design firm) in a given year.[12]

Summary statistics for our key variables are shown in the Appendix. The top panel of Table A1 is based on our universe of firms from 1965 to 1997, and the bottom panel is based on the sample we use for estimation. The median firm in our sample is 24 years old in 1995, has approximately 500 employees, spends five million (1992) dollars on R&D, and successfully applies for one patent a year. The distribution of these variables is quite skewed, however, with over 700 patent applications in one year for one firm (Texas Instruments in 1995) and over one billion dollars of R&D in one year for one firm (Intel in 1994 and 1995). Design firms represent 20% of the observations.

□ **Estimating the patent production function.** To explore the determinants of patenting in these semiconductor firms and how they have changed over time, we use a patent production function first introduced by Pakes and Griliches (1980); our specific econometric model was first applied to patent data by Hausman, Hall, and Griliches (1984). The patent production function relates the number of successful patent applications made by a firm in a given year to its past history of R&D spending, along with other firm characteristics such as size.

Because the number of successful patent applications made by a semiconductor firm is a count variable with many zeroes and ones, we use Poisson-based econometric models and estimation methods. As in Hausman, Hall, and Griliches (1984), we hypothesize that the expected number of patents applied for during the year is an exponential function of the firm's R&D spending and other characteristics X_{it}:

$$E[p_{it}|X_{it}] = \lambda_{it} = \exp(X_{it}\beta + \gamma_t),$$

where i indexes the firm and t indexes the year. γ_t is an overall year-specific mean that measures the average patenting rate across all firms, adjusting for the changing mix of firms in the sample. We estimate this model using maximum likelihood for the Poisson distribution, but we report "robust" standard errors. Gourieroux, Montfort, and Trognon (1984) have shown that because the Poisson model is in the linear exponential class, the Poisson coefficient estimates are consistent if the mean specification is correct and the robust standard errors are consistent even under misspecification of the distribution.

[12] We identified founding years using business directories in Lexis-Nexis and determined whether each firm owned and operated its own fabrication facilities (or specialized in chip design) by using historic volumes of ICE "Status Reports" (1975–1998) and the background section of annual 10-K filings.

We also report the results of a Lagrange multiplier test due to Cameron and Trivedi (1998) for overdispersion of the negative binomial (2) type.[13] Rejection can be interpreted as a rejection of the pure Poisson model in favor of a model where the variance is proportional to the mean. But because the negative binomial model estimates would be *inconsistent* if the true distribution were *not* negative binomial, we prefer to interpret the LM test as a diagnostic that indicates that we should report robust, heteroskedastic-consistent standard errors for the Poisson model (which will remain consistent) rather than implying that we should automatically switch to a negative binomial model (which is potentially inconsistent).

The coefficients from the patent production function model presented above have an elasticity interpretation,

$$(1/\lambda_{it})(d\lambda_{it}/dX_{it}) = \beta,$$

and the changes in the γ_t's measure the growth of the patenting propensities over time that is not accounted for by changes in the firm's characteristics:

$$\Delta \log \lambda_{it} = X_{it}\beta + \gamma_t - (X_{it-1}\beta + \gamma_{t-1}) = \Delta X_{it}\beta + \gamma_t - \gamma_{t-1}.$$

Thus the growth of the expected number of patents can be decomposed into the growth due to changes in firm characteristics and a residual growth rate $\gamma_t - \gamma_{t-1}$, which we interpret as being due to changes in the patenting environment faced by these firms.

Traditionally, the most important variable in the patent production function is R&D spending by the firm. Much of the early work that estimated this model focused on the question of whether one could measure the lag structure for the production of patents from past R&D spending (Pakes and Griliches, 1980; Hausman, Hall, and Griliches, 1984; Hall, Griliches, and Hausman, 1986; see also Montalvo, 1997 and Blundell, Griffith, and Windmeijer, 2000). This literature largely concludes that the lag structure is very poorly identified because of the high within-firm correlation of R&D spending over time. When many lags are included in the model, the estimate of the sum of the coefficients is roughly the same as the estimated coefficient of contemporaneous R&D when no lags are included; in addition, most of the contribution comes from the oldest and the newest R&D lag included. Experimentation with lag structures using these data confirmed the results in the earlier literature. For this reason and because many of our firms have very short R&D histories, we use contemporaneous levels of R&D spending in our specifications.

A second result in the previous literature on patent production is that when one allows for permanent differences across firms in the propensity to patent, the sum of the R&D lag coefficients falls, mostly because the coefficient on the oldest lag becomes insignificant. For some of our hypotheses, we are interested in the firm effects themselves (for example, the difference between design and manufacturing firms, or the difference between incumbents and entrants). With this in mind, we do not want to begin with a model that sweeps them out. To determine whether the coefficients are biased from the presence of unobserved firm characteristics, however, we ran separate analyses using the conditional (fixed-effect) and random-effects Poisson models introduced by Hausman, Hall, and Griliches (1984). In contrast to earlier results using these

[13] All the estimates in the article were obtained using the POISSON, NEGBIN, and ML procedures in TSP Version 4.5. See the *TSP Reference Manual* (1999) for details on the estimation strategy. The results were benchmarked against published results in Cameron and Trivedi (1998) and Hausman, Hall, and Griliches (1984).

kinds of data that were based on a wide range of industries, we found that the impact of permanent differences across firms within this single industry was in fact quite modest. For these reasons, we allow for observed permanent differences across firm types in the analyses reported in this article, but we do not include unobserved firm effects.[14]

Our base specification of the patent production function therefore includes the following variables:

R&D spending during the year in which the patent applications were filed, deflated in 1992 dollars, in logarithms. When employment (size) is also included, we normalize R&D spending by the number of employees to avoid confounding the R&D effect with the size effect. For a small number of observations, R&D is missing or not reported; we include a dummy variable for these observations so that the R&D coefficient will not be biased.

The *size* of the firm, measured as the logarithm of employment. As previous studies have documented, there may be economies of scale in generating patents due to the fixed cost of maintaining a legal department that handles IP (Intellectual Property)-related questions and tasks (confirmed in our interviews; see also Lanjouw and Lerner (1996) and Lerner, (1995)).

Annual time dummies for 1979–1995.

After presenting the base specification and discussing the results, we estimate a series of "patent production functions" that (i) illuminate whether a change in firm-level patenting behavior has taken place during the period associated with stronger U.S. patent rights, as suggested by the general trends shown earlier in Figure 1, and (ii) explore key differences among firms. Recall that we seek to test two main hypotheses. First, we examine whether firms most subject to "holdup" responded strategically to the shift in the U.S. legal environment by patenting more aggressively during the period of strong patent rights (our strategic response hypothesis). Based on our interviews, firms with large sunk costs in complex manufacturing facilities appear to have the largest incentives to "ramp up" their patent portfolios to safeguard against the threat of costly litigation and to negotiate access to external technologies on more favorable terms. To test this hypothesis, we ask whether capital intensity (a stock measure, defined below) influences the patenting behavior of firms in this industry and whether it has played a more prominent role in their patenting behavior in the period of strong U.S. patent rights.

To test our second main hypothesis—that patent rights facilitated entry by design firms that rely more heavily on patents to appropriate returns to innovation (our specialization hypothesis)—we will (1) examine the changing pattern of entry in this industry and (2) investigate whether post-1982 design firms (i.e., ones that entered the industry during the pro-patent era) rely more heavily on patent protection, controlling for other determinants of patenting. Finally, to address the alternative "regulatory capture" hypothesis posed by Kortum and Lerner (1998), we control for the one firm in our sample, Texas Instruments, that held a large portfolio of patents in the pre-1982 period (both in absolute numbers and relative to other firms in the sample). This hypothesis also implies more aggressive patenting by large incumbents, an issue that we also explore. We return to the second alternative hypothesis raised by Kortum and Lerner (that the patterns we observe are driven by improvements in the research process unrelated to stronger U.S. patents) in Section 5.

[14] The results of our analyses of firm effects are available in Appendix C of an earlier version of our article (see footnote 7).

In summary, to test our hypotheses, we augment the base specification outlined above with a series of variables that explore the differences in the patent equation for firms of various types:

The *capital intensity* of the firm, measured as the logarithm of the ratio of deflated (1992$) property, plant, and equipment to employees (i.e., capital-labor ratio).

An *entrant dummy,* for firms that were founded after 1982 (the year that CAFC was created). There are 35 such firms with 185 observations.

The *type* of firm (manufacturer or design firm). There are 28 design firms in the sample for a total of 192 observations.

A *Texas Instruments* dummy, to control for the fact that TI patents aggressively relative to other firms in our sample, controlling for R&D spending and size.

The *age* of the firm (measured as the logarithm of the difference between the current year and the founding year of the firm) to control for the possibility that older firms have more experience managing the patent application process and therefore may be more efficient in their patenting activities for reasons that are not perfectly correlated with firm size (Sorensen and Stuart, 2000).

□ **Basic results.** Table 1 presents a series of estimations of our basic model using maximum-likelihood methods and the Poisson density function. As should be clear from the above discussion, the dataset is a panel and the unit of analysis is a firm-year. Standard error estimates robust to heteroskedasticity and misspecification of the distribution are shown in parentheses. Column 1 shows that the estimated elasticity of patenting with respect to R&D spending in this industry is similar to estimates previously obtained using data for the whole manufacturing sector in the 1970s, although somewhat higher. For example, Hausman, Hall, and Griliches (1984) obtained an R&D elasticity of .87 (.004) using the Poisson distribution and an elasticity of .75 (.02) and variance parameter of .04 (.002) using the negative binomial distribution for 128 large firms. Hall, Griliches, and Hausman (1986) obtained a somewhat lower elasticity of .52 for a larger sample of 642 firms. In the latter case, the log of capital stock was also included in the equation, and the total scale coefficient (the sum of the two coefficients) was .66, somewhat closer to our estimate of .99 (.04).

When we add firm size and capital intensity to the model and replace R&D with the R&D-employment ratio in column 2, the R&D coefficient falls sharply because the size effect is now in the employment variable, but the scale coefficient is about the same (equal to .96). That is, there is no evidence of increasing returns in the patent production function. The explanatory power of the model also improves, with a substantial increase in the likelihood and a fall in the value of the overdispersion test statistic. Capital intensity seems to have an important effect on the propensity to patent, one that is slightly larger and more significant than the influence of R&D spending. This is consistent with our first (strategic response) hypothesis.

In column 3 we add dummies for post-1982 entry and for Texas Instruments (TI). The estimate for TI reflects its well-known aggressive IP strategy and suggests that TI obtains an average of approximately 122% more patents (= exp(.799) − 1) than other firms in the sample, even controlling for its size, R&D, and capital intensity. In column 3 and in the rest of our results, the patent equation is much closer to passing the overdispersion test. Controlling for the unique nature of TI leaves us with a sample of firms whose patenting behavior is more consistent with the conditional Poisson model (that is, the variance conditional on firm characteristics is nearly equal to the conditional mean). Interestingly, firms that entered this industry during the pro-patent era have a 65% higher patenting propensity. Allowing for this fact also strengthens the impact of

TABLE 1 Patenting Propensity Estimates
U.S. Semiconductor Firms 1979–1995 (946 observations)

Variable Name	Poisson (1)	Poisson (2)	Poisson (3)	Poisson (4)
Log R&D ($1992M) or log R&D per employee ($1992 1000s)	.989 (.036)	.179 (.088)	.190 (.084)	.196 (.117)
Dummy for no reported R&D	−1.390 (.800)	−1.680 (.833)	−1.690 (.830)	−1.690 (.840)
Log firm size (1000s employees)		.956 (.025)	.854 (.032)	.850 (.034)
Log P&E per employee ($1992K)		.341 (.121)	.601 (.113)	.603 (.114)
Dummy for post-1982 entrants			.491 (.169)	.503 (.199)
Dummy (Texas Instruments)			.799 (.111)	.798 (.115)
Dummy for firms without fabrication plants (design)				−.013 (.185)
Log firm age (number of years)				.022 (.146)
Test for overdispersion (p-value)	52.4 (.000)	44.0 (.000)	16.8 (.000)	16.7 (.000)
Log-likelihood	−6059	−4825.8	−4132.7	−4132.5
Number of parameters	19	21	23	25
χ^2 (p-value)	802.8 (.000)	45.1 (.000)	75.9 (.000)	.024 (.987)

Notes: Log R&D in column 1; log R&D per employee in the other columns. Heteroskedastic-consistent standard errors are shown in parentheses. The method of estimation is maximum likelihood for the Poisson model (which is generalized ML for the exponential mean function). The χ^2 is a Wald test for the specification in the column to the left versus the current column.

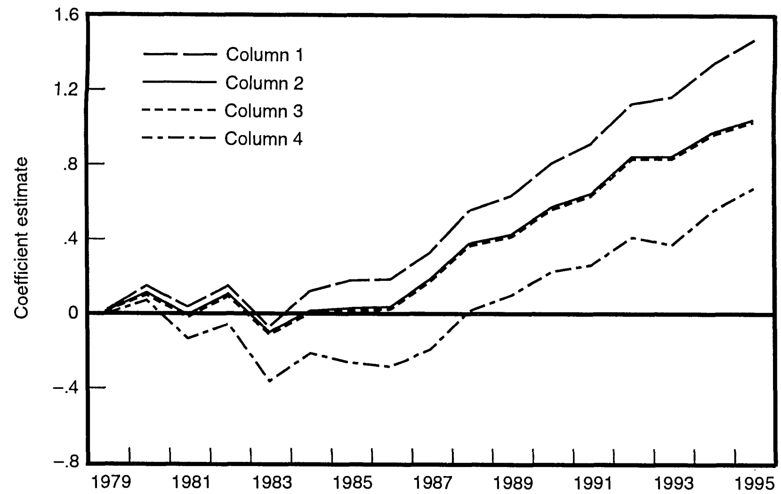
capital intensity. Later on, we provide evidence that this is because many of the new entrants are design firms, which patent relatively heavily but do not have manufacturing plants (consistent with our second hypothesis, specialization).

The final column of Table 1 shows that neither the age of the firm nor whether it is a design firm influences the propensity to patent, once we have controlled for the firms that enter in the pro-patent era (after 1982). It is essential to note that this would *not* be the case if we had omitted the post-1982 entrant dummy. We interpret this finding in part as a contradiction to the Kortum and Lerner "regulatory capture" hypothesis (for which they too find little support), which implies that incumbents should have a higher patenting propensity than entrants. Because the age of the firm and whether it is a design firm do not enter significantly in this equation, we use the specification given in column 3 of this table for the remainder of this article. We will revisit the design firm question more closely, however, in Table 3.

The estimates in Table 1 yield another striking result, as shown in Figure 2. This figure plots the year dummies for the four sets of estimates, normalized so that they are equal in 1979. That is, $\gamma_t - \gamma_{1979}$ is plotted. These estimates make it quite clear

FIGURE 2

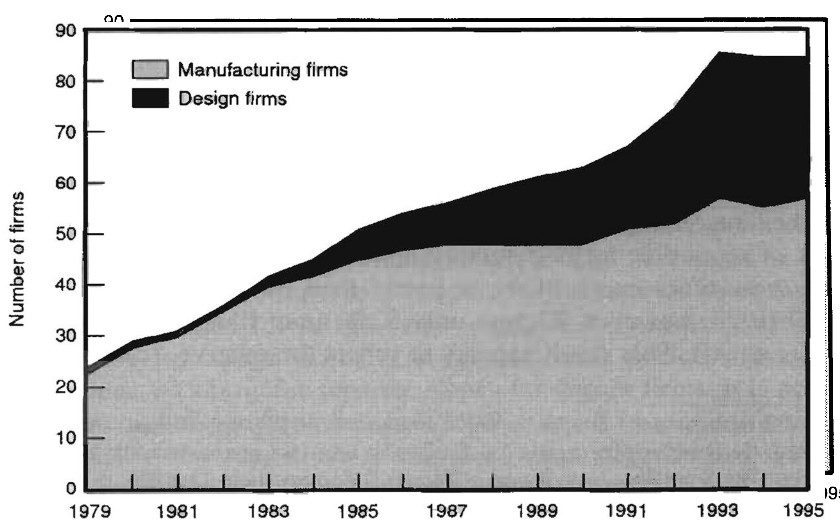
ESTIMATED YEAR EFFECTS (FROM TABLE 1)



that controlling for changes in the mix of semiconductor firms over time does not undermine the rise in patenting propensity shown in Figure 3. The patent propensity of the firms in our sample increased at a steady rate of 10% per year after about 1986, somewhat later than the 1982 introduction of the Court of Appeals for the Federal Circuit, for a total increase of approximately 100% by 1995. These results are consistent with the views expressed by industry representatives that the events most significant in altering their firms' behavior were the well-publicized Kodak-Polaroid case (1986) and the aggressive stance of TI with respect to its patent rights (which dates to about 1985–1986), rather than the 1982 formation of the CAFC in itself. Our overall conclusion from Table 1 is that an overall shift in behavior has occurred, capital intensity

FIGURE 3

TYPES OF SEMICONDUCTOR FIRMS IN SAMPLE



is an important predictor of patenting behavior and entrants patent more than incumbents, other things equal.

□ **Changes in the determinants of patenting.** To examine whether the pro-patent shift in the U.S. legal environment altered the determinants of patenting for firms in this industry, we would like to estimate the behavior of these firms in periods both before and after the "regime shift" took place. But the actual strengthening of U.S. patent rights involved a gradual process by which court rulings were disseminated and upheld. Although the CAFC was created in 1982 and issued a flurry of written opinions during 1983 (Adelman, 1987; Nies, 1993), the impact of the CAFC on the favorable legal treatment of patent rights in U.S. courts was not widely publicized until the mid-1980s.[15] Representatives from semiconductor firms also emphasized the important "demonstration effects" associated with the successful patent infringement suits of Texas Instruments and Polaroid during 1985–1986, as discussed in Section 3.

With this in mind, we selected three five-year intervals that allow for a more gradual "regime shift" toward stronger U.S. patent rights. The first period, 1979–1983, examines the patenting behavior of firms under the weaker patent regime. It implicitly assumes that the response of firms to the 1982 creation of the CAFC would require at least a one-year lag.[16] The "during" period, 1984–1988, spans years in which the more favorable judicial stance toward patents of the CAFC was widely heralded in the trade and business prèss and verdicts in the TI and Polaroid cases were reached. The final period, 1989–1993, examines the determinants of patenting under the pro-patent regime.

To examine *changes* in the determinants of patenting across the three periods, we restrict the sample to the subset of semiconductor firms that were publicly traded before 1984 and for which data were available in each of the three periods. This selection criterion generated a sample of 34 incumbent firms. Table 2 presents the estimates of these incumbents' patenting behavior in each of the three five-year intervals—again using maximum-likelihood methods, a Poisson density function, and standard errors that are robust to heteroskedasticity and misspecification of the distribution. The results were insensitive to a more restrictive definition of "incumbents" that included firms publicly traded before 1983 (instead of 1984) and the inclusion of eight incumbents that exited the sample during periods 2 and 3.

Overall, the results in Table 2 suggest that the strengthening of U.S. patent rights has indeed altered the incentives of firms to patent, but for reasons that transcend those implied by a narrow conception of patents as a mechanism by which to appropriate returns to R&D. During the era of strong patent rights, these firms' patenting behavior became *less,* not more, responsive to their investments in R&D. Consistent with the view that capital-intensive firms *altered* their behavior under the new pro-patent regime by patenting more aggressively, the coefficient of capital intensity changed from small and insignificant in periods 1 and 2 to positive and highly significant in period 3.

Two other interesting results are contained in Table 3. First, Texas Instruments became less of an outlier in its patenting behavior over time. During 1979–1988, TI was two to three times more likely to patent than other incumbents, all else equal. During 1989–1993, however, TI was only 92% more likely to patent that the other firms (all else equal). This result appears to reflect the relative "catching up" by other

[15] A series of business press articles appeared around 1985–1986, announcing "A Change in the Legal Climate," *Forbes,* October 7, 1985, p. 41; "A Weapon at Last [pro-patent decisions]," *Forbes,* March 10, 1986, p. 46; and "The Surprising New Power of Patents," *Fortune,* June 23, 1986, p. 57.

[16] Excluding 1983 from this period did not substantively alter the results.

TABLE 2 Changes in the Determinants of Patenting U.S. Semiconductor Firms Pre-1984 Incumbents, Five-Year Time Intervals

Variable Name	Period 1: 1979–1983 "Before" Poisson (1)	Period 2: 1984–1988 "During" Poisson (2)	Period 3: 1989–1993 "After" Poisson (3)
Log R&D per employee ($1992 1000s)	.457 (.199)	.530 (.200)	.041 (.125)
Log firm size (1000s employees)	.800 (.056)	.880 (.048)	.887 (.074)
Log P&E per employee ($1992 1000s)	−.030 (.237)	.128 (.184)	.574 (.177)
Dummy (Texas Instruments)	1.094 (.186)	.940 (.117)	.654 (.209)
Number of observations	127	169	164
Overdispersion test (p-value)	.32 (.573)	.59 (.443)	.13 (.719)
Log-likelihood	−278	−547.3	−848
Robust Wald test (p-value)		1.82 (.769)	10.3 (.035)

Notes: Sample includes 34 firms publicly traded before 1984 and for which data were available in all three periods. All estimates include a full set of year dummies. Heteroskedastic-consistent standard errors are shown in parentheses. 14 observations for firms that did not perform R&D have been deleted. The Wald tests are for equality of column 2 or 3 slope coefficients with those of column 1.

incumbents, rather than a fall or levelling off in TI's absolute propensity to patent during the 1989–1993 period. A second interesting finding pertains to the relative stability of the size coefficient across the three periods, which casts further doubt on the "regulatory capture" hypothesis. Although large firms might enjoy economies of scale in applying for and enforcing patents, the elasticity of patenting with respect to firm size is quite similar in each period and remains somewhat less than unity.

□ **Manufacturing versus design firms.** In Table 3, we revisit the question of whether the increase in patenting was driven by changes in the behavior of capital-intensive manufacturers, by the patenting behavior of an increasing number of design firms, or both. To explore this question, we tried four variations of our basic specification: a separate intercept for design firms, different slopes for the two groups, separate trends, and separate trends and slopes. Robust χ^2 tests rejected all hypotheses of coefficient equality, implying that a completely different patenting propensity equation is appropriate for the two groups of firms. We show the estimates that allow for separate trends and slopes in Table 3.

Two results in the table reinforce the view that stronger patent rights facilitated entry into the industry by specialized design firms for which capital intensity is a relatively unimportant predictor of patenting behavior. The first result is, not surprisingly, that capital intensity is a much more important predictor of patenting propensity for manufacturing firms than for design firms (compare the elasticity of .64 for manufacturers versus .30 for design firms). The second result, which is even more pronounced, is that once we allow for separate slopes for design firms, it is not post-1982 entry that predicts higher patenting but post-1982 entry *by a design firm,* with a coefficient of 1.60 (.27). The magnitude of this coefficient suggests that these firms are almost five times more likely to patent than the rest of the sample, controlling for their

TABLE 3 **Patenting Propensity Estimates U.S. Semiconductor Firms 1979–1995 (95 firms, 946 observations)**

Manufacturing firm coefficients	
Log R&D per employee ($1992 1000s)	.168 (.117)
Dummy for no reported R&D	−1.805 (.843)
Log firm size (1000s employees)	.830 (.035)
Log P&E per employee ($1992 1000s)	.639 (.137)
Dummy for post-1982 entrants	.129 (.254)
Dummy (Texas Instruments)	.833 (.122)
Design firm coefficients	
Log R&D per employee ($1992 1000s)	.265 (.231)
Log firm size (1000s employees)	.896 (.065)
Log P&E per employee ($1992 1000s)	.301 (.153)
Dummy for post-1982 entrants	1.600 (.274)
Test for overdispersion (p-value)	17.1 (.000)
Log-likelihood	−3968.2
Number of parameters	44
χ^2 (df = 4) (p-value)	20.9 (.000)

See notes to Table 2. Two separate sets of year dummies for manufacturing and design firms are included in the estimation. The χ^2 test is for the hypothesis that the manufacturing and design firm slope coefficients differ.

other characteristics.[17] We view this as strong confirmation of our interviewees' statements that patent rights are required to secure venture capital and other financing for entry as a specialized semiconductor design firm.

A second piece of evidence on this question is provided in Figure 3, which shows the cumulative entry of both manufacturers and design firms into our sample. As can be seen from the figure, few design firms enter before 1986, and then the number surges upward (the curve flattens out in 1993 because of our requirement that a firm have three good years of data to be in our sample). Although this entry was enabled by the transition to the MOS standard and the availability of foundry providers (Macher, Mowery, and Hodges, 1998), it is possible that the consequent fragmentation of the design and production process was facilitated by access to stronger patent rights.

[17] A sufficient number of firm-year observations (89) were based on design firms founded before 1982, which allows for this equation to be well identified.

□ **Summary of econometric results.** Our econometric study identifies at least two reasons for the surge in patenting per R&D dollar in the semiconductor industry since the mid-1980s: increased patenting by capital-intensive manufacturing firms and increased entry into the industry by design firms that need patents on their technology to secure financing. But which of these two is driving the aggregate patterns we observe in this industry? Figure 4 provides an answer. This figure shows the patent-R&D ratio (weighted by R&D spending) for all firms in the industry and for manufacturers and design firms separately.[18] The increase in this ratio in manufacturing tracks the ratio for the whole industry closely, whereas for design firms, the ratio is constant or even falling. Because the R&D in design firms is only 15% of the total R&D in the industry even in the later years, patents per R&D dollar weighted by R&D spending will be dominated by changes in the manufacturing part of the industry. Even though the pro-patent shift may have facilitated vertical disintegration in this industry, the primary reason for the aggregate increase in patenting per R&D dollar is more aggressive patenting by manufacturers in our sample.

5. Exploring alternative hypotheses

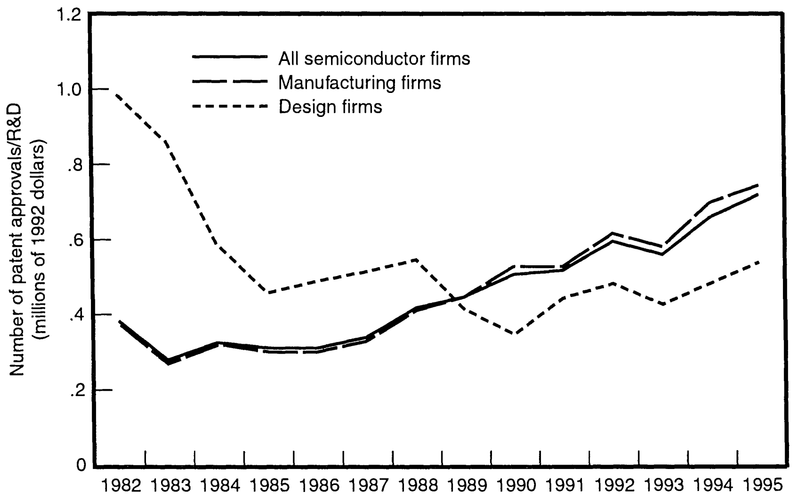
■ In previous sections we have demonstrated that a surge in the patent propensities of semiconductor firms has occurred during the period associated with stronger U.S. patent rights, and that the surge is driven by more aggressive patenting by large-scale manufacturers in our sample. In our opinion, these results are consistent with a variant of Kortum and Lerner's "friendly court" hypothesis, but one that allows for strategic behavior among firms. In an industry where the pace of technology is rapid, and innovation is cumulative, the strengthening of patent rights increases the risk that one holder of property rights can effectively exclude, or "block," another from using the technology embodied in the patent (Merges and Nelson, 1990; Cohen, Nelson, and Walsh, 2000). This concern appears especially salient among firms that have made costly and rapidly depreciating investments in facilities that use a "thicket" of innovations developed by many parties. To obtain the rights to infringe patents held by external parties and to improve their leverage in negotiations with other patent owners, these firms amass larger patent portfolios of their own with which to trade. With the strengthening of U.S. patent rights, the expected benefits of owning U.S. patents (for offensive and defensive reasons) began to outweigh their expected costs.

Although our empirical results and interviews with firms suggest that intensified patenting in this industry was driven by the pro-patent shift in the U.S. legal environment, it is important to address whether the patterns we observe stem from unrelated managerial or technological improvements, as suggested more generally by Kortum and Lerner (1998). First, if firms have redirected more of their R&D investments toward applied rather than basic research, we might also see an increased patent yield of R&D dollars over time. There was little indication from our interviews that such an industrywide shift occurred that would explain the time trends we observe. We did, however, find a general belief that it is remarkably easy for these firms to obtain patent rights from the U.S. Patent and Trademark Office. In the view of most representatives and executives we interviewed, the standards of patentability have been lowered too far (especially the standard that an invention must be "nonobvious" to be eligible for a

[18] The data in this figure are shown beginning in 1982 because there are very few design firms in the sample prior to that date (fewer than five). The few that are there have a very high yield of patents to R&D, which makes the rest of the graph hard to see if they are included.

FIGURE 4

PATENTS PER MILLION R&D DOLLARS: SAMPLE FIRMS



patent award).[19] Although the ease with which firms may obtain U.S. patents may have increased over time, there is little reason to believe that procedures at USPTO would favor patenting in semiconductor-related technologies in ways that would explain the disproportionate surge in patenting by firms in this industry.

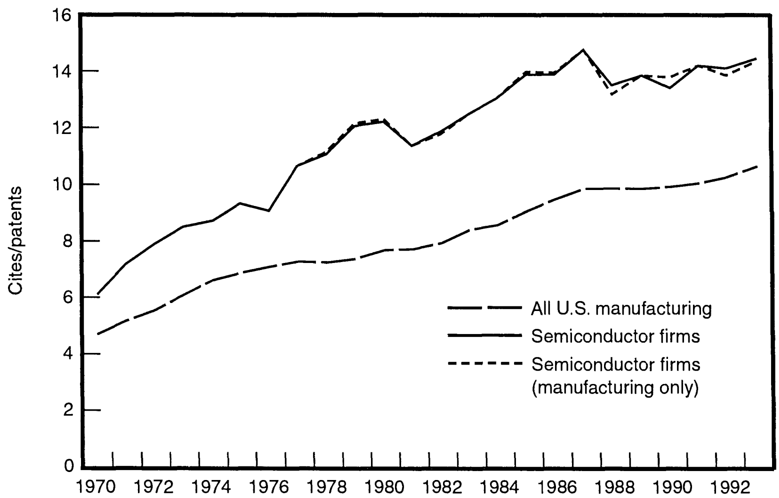
A related explanation for the surge in patenting is that firms have improved their ability to manage the innovation process and that the "productivity of R&D" has therefore improved. Put differently, R&D expenditures may have remained relatively stable while the patented "output" of that R&D has increased due to managerial or technological improvements in the innovation process that are unrelated to the change in U.S. patent policies. Through a process of elimination, Kortum and Lerner (1998) supported the view that these unrelated managerial improvements (not the "friendly court" or a shift toward applied research) underpinned the cross-industry increase in U.S. patenting.

Our interviews suggest a very different interpretation of this "unrelated R&D productivity" hypothesis, at least as it pertains to managerial improvements in the semiconductor industry. The shift in patenting relative to R&D spending since the mid-1980s may indeed reflect important managerial changes, but primarily in how firms manage the *R&D output,* not necessarily the *R&D input* side of the innovation process. For example, several firms had overhauled their internal patent procedures during the past 5–10 years by hiring more in-house patent attorneys, rewarding engineers with bonuses for patented inventions, expanding the involvement of patent attorneys in corporatewide activities (such as strategic alliances, licensing, and litigation decisions), and creating in-house "patent committees" to oversee and simplify the otherwise time-consuming process of writing, filing, and revising patent applications. As mentioned earlier, manufacturers appeared to be "harvesting" more of their latent inventions and explicitly "ramping up" their patent filings in order to amass more sizeable patent portfolios. Although the increased sophistication of design tools may have aided many

[19] Hunt (1999) examines this apparent lowering of "nonobviousness" standards in the United States during the 1980s. The combined effect of (a) strengthening patent enforcement and (b) lowering patentability requirements is an interesting topic for future research.

FIGURE 5

AVERAGE "QUALITY" OF SEMICONDUCTOR PATENTS (MEASURED BY FORWARD CITATIONS)



of these firms' abilities to innovate in product areas, the most dramatic alteration in internal processes appeared to be directed toward the management of the patent process itself.

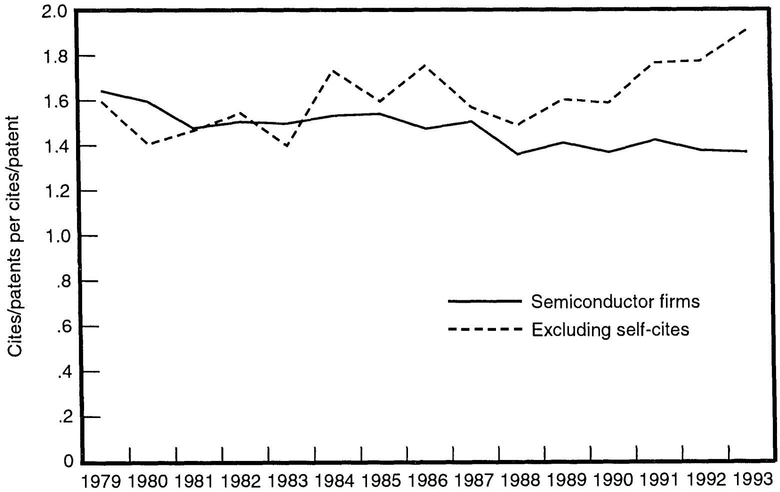
To test whether firms are applying for an increasing number of "lesser quality" patents over time (as implied by a "harvesting" strategy whereby firms are increasing their filings of marginal patent applications), or whether the quality of their patent portfolios remains relatively constant over time (as implied by an increase in research productivity alone), we examine changes in the relative "quality" of these firms' patents over time. We use two very imperfect measures of patent "quality." The number of citations received by the patent ("forward" citations) and the number of claims in the patent. There is considerable support in the literature for the idea that the former measure is correlated with the private value of the patentable invention (see Harhoff et al. (1999) and Hall, Jaffe, and Trajtenberg (2000) among others). Lanjouw and Schankerman (1999) show that forward citations and claims are among the several correlated indicators of private value. It is also true, however, that these indicators may be changing over time for reasons unrelated to quality. To control for secular changes in patenting and citation behavior, we compare the changes in these measures for our firms to corresponding changes for U.S. manufacturers overall.

Our evidence is weakly consistent with a "harvesting" strategy, but it is sensitive to the quality measures employed. Using the average citations per patent measure, we find a slight decline in the average quality of our firms' patents since 1984, relative to the average quality of patents assigned to U.S. manufacturers as a whole. Figure 5 shows that although semiconductor patents in general receive more citations than the average patent in manufacturing, the relative ratio fell from 1.5 to 1.4 during the 1980s.[20] This result is consistent with the view that firms are filing larger numbers of

[20] We do not report significance levels for this finding due to the large number of observations involved, which means that the average citation-patent ratio is extremely well determined and almost any point hypothesis would be rejected.

FIGURE 6

AVERAGE "QUALITY" OF SEMICONDUCTOR PATENTS (INCLUDING AND EXCLUDING SELF-CITATIONS)



lower-quality patents during the period associated with stronger patent rights, in contrast to what the "unrelated R&D productivity" hypothesis would imply.[21]

However, Figure 6 shows this relative citation-per-patent measure with and without self-citations (citations from patents held by the same firm). The propensity that other firms will cite patents held by semiconductor firms is clearly rising, which could result if the increased likelihood of litigation in this industry has led to an increase in "defensive" citation aimed at delimiting more clearly the boundaries of the invention covered by the patent (see Jaffe, Tratjenberg, and Fogarty (2000)). Thus, we conclude that in the case of semiconductors and the pro-patent legal shift, changes in citations per patent potentially confound two opposite effects: declines due to lower-quality patents and increases due to "defensive" citation, rendering it difficult to draw definitive conclusions about the increased propensity to "harvest" inventions from this measure. We also found little evidence of either an increase or a decrease in patent quality over this period based on the average claims per patent by our semiconductor firms relative to the average for all manufacturing. If anything, the ratio seems to have risen slightly in the early 1980s and then flattened out.[22]

Our conclusion from the examination of citations and claims for these semiconductor patents is that there is weak evidence at best for the hypothesis suggested by our interviewees, that the quality of the average patent in this industry has fallen. However, we caution that these measures are highly imperfect and contaminated by other changes in patenting strategy during the period. This is clearly an area for future research.

[21] We estimated citation lag distributions (see Jaffe and Trajtenberg, 1996) and broke out semiconductors pre- and post-1984 from the other technologies. The results (not shown) rejected hypotheses that semiconductors have the same citation distribution as other industries and that post-1984 semiconductor patents have the same citation distribution as pre-1984 patents.

[22] These results demonstrate the challenge of constructing representative "control" groups. An alternative approach could compare changes in our sample firms' patent filings in the United States with their filings in a patent system that screens out marginal patent applications more carefully (e.g., the European or German patent offices).

6. Conclusion

■ A patent is a legal right to exclude. In an industry where the pace of technology is rapid and firms advance quickly (even simultaneously) upon innovations made by others, firms may patent for strategic reasons even if they continue to rely on other mechanisms, such as lead time and superior manufacturing or design capabilities, to recoup investments in R&D. Especially for firms engaged in rapidly changing, cumulative technologies, building larger portfolios of their own "legal rights to exclude" may reduce the holdup problem posed by external patent owners and enable firms to negotiate access to external technologies on more favorable terms. But the importance of patent rights and their use may vary among firms even within one industry over time.

This article examined the patenting behavior of firms in one "cumulative innovation" setting, semiconductors, where the gap between the relative ineffectiveness of patents as a means to profit from innovation (as reported in surveys) and their increasing use is particularly striking. By combining insights from interviews with intellectual property managers and executives from semiconductor firms with quantitative analyses of the patenting behavior of 95 U.S. firms during 1979–1995, we identified two ways in which the pro-patent shift in the U.S. legal environment appears to be causally related to the otherwise perplexing surge in U.S. patenting rates, at least in the semiconductor industry. First, stronger patent rights may have facilitated entry by specialized firms and contributed to vertical disintegration in this industry (Merges, 1997; Arora and Fosfuri, 1998). But these positive effects coincide with a process whereby firms amass vast patent portfolios simply as "bargaining chips," leading to "patent portfolio races." In principle, such racing behavior is not an inevitable outcome of strengthening patent rights in cumulative technological areas. If patent rights were strictly awarded to inventors of "nonobvious," "useful," and "novel" inventions, then it should become increasingly difficult to obtain a patent when a thicket of prior art exists, and the number of successful patent applications should fall. This is not, however, what we observe in this industry.

Our study highlights the multifaceted effects of strengthening patent rights on firms even within one cumulative technological setting. It also leaves a number of important questions unresolved. What are the overall social welfare consequences associated with the type of "patent portfolio races" that we observe in this industry? Does this behavior simply represent the outcome of a noncooperative strategic game and, therefore, an implicit "tax" on innovation? Or do these portfolios provide an important backdrop for exchanges of intellectual property and more tacit "know-how" that otherwise would not take place? Under what conditions do the social costs associated with "patent portfolio races" begin to outweigh other associated benefits? The results of our study underscore the importance of continued theoretical and empirical research on the effects of strong patent rights in technological settings where innovation is inherently cumulative but firms also rely on mechanisms other than patents to appropriate returns to R&D.

Appendix

■ Table A1 provides summary statistics for the overall sample of 110 U.S. semiconductor firms and the sample of 95 firms used in the regressions.

TABLE A1 Sample Statistics

Variable Name	Mean	Standard Deviation	Median	First Q	Third Q	Minimum	Maximum
U.S. semiconductor sample before cleaning[a]							
Patent applications	11.1	43.68	1	0	4	0	565
R&D ($M 1992)[c]	4.77	2.14	4.63	.55	15.05	0	2116.8
Employment (1000s)[c]	.645	1.77	.551	.192	1.797	0	89.9
P&E per employee[c] ($1000 1992)	21.7	.84	24	13.1	43.6	.8	252.8
Age of firm	24.4	12.9	22	13	35	3	60
D(R&D = 0)	.069	(N = 105)					
D(entered after 1982)	.298	(N = 454)					
D(design firms)	.199	(N = 303)					
U.S. semiconductor sample used in regressions[b]							
Patent applications	17.62	64.86	1	0	6	0	768
R&D ($M 1992)[c]	4.98	2.13	5.75	.74	16.83	0	1212.6
Employment (1000s)[c]	.537	1.74	.491	.16	1.46	0	89.9
P&E per employee[c] ($1000 1992)	24.4	.91	26.8	13.2	46.1	.4	247.1
Age of firm in 1995	24	11.7	24	14	33	3	59
D(R&D = 0)	.042	(N = 40)					
D(entered after 1982)[d]	.196	(N = 185)					
D(design firm)[d]	.203	(N = 192)					

[a] 1,525 observations (110 firms), 1965–1997.
[b] 946 observations (95 firms), 1979–1995.
[c] Geometric means are shown for these variables, along with the standard deviation of the log.
[d] The intersection of design firms and post-1982 entry contains 103 observations.

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