EXPLORING THE PATENT EXPLOSION

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Abstract
This paper looks more closely at the sources of patent growth in the United States since 1984. It confirms that the increase is largely due to US patenters, with an earlier surge in Asia, and some increase in Europe. Growth has taken place in all technologies, but not in all industries, being concentrated in the electrical, electronics, computing, and scientific instruments industries. It then examines whether these patents are valued by the market. We know from survey evidence that patents in these industries are not usually considered important for appropriability, but are sometimes considered necessary to secure financing for entering the industry. I compare the market value of patents held by entrant firms to those held by incumbents (controlling for R&D). Using data on publicly traded firms 1980-1989, I find that in industries based on electrical and mechanical technologies the market value of entrants' patents is positive in the post-1984 period (after the patenting surge), but not before, when patents were relatively unimportant in these industries. Also, the value of patent rights in complex product industries (where each product relies on many patents held by a number of other firms) is much higher for entrants than incumbents in the post-1984 period. For discrete product industries (where each product relies on only a few patents, and where the importance of patents for appropriability has traditionally been higher), there is no difference between incumbents and entrants.

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My first meeting with Ed Mansfield was in 1980, when he discussed the paper I presented on patenting in the computer and drug industries (which was ultimately published with data on all manufacturing industries, as Bound et al 1984, in the volume from that conference edited by Zvi Griliches). At that time, his unpublished discussion emphasized the difference between these two

industries in the importance and relevance of patents as a measure of innovation. This was the first time I learned about what is now called the distinction between discrete and complex product industries. Although the use of patents in the two types of industries has certainly changed since that time, they are still quite different in their patenting behavior, as I hope this paper shows. I think Ed would have particularly liked the fact that this paper was motivated by interviews with those in the electronics industry (Hall and Ziedonis 2001; Ziedonis and Hall 2001), something he always encouraged me to undertake.

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Exploring the Patent Explosion

1 Introduction

A number of researchers have explored the reasons behind the recent rapid growth of patenting worldwide and especially in the United States (Kortum and Lerner 1995, 2003; Hall and Ziedonis 2001; Kim and Marschke 2004). Various explanations for the phenomenon have been offered: using aggregate US and international patent data, Kortum and Lerner attribute most of the growth to increases in innovation and improvements in the management of R&D. Using data on U.S. firms during the 1983-1992 period, Kim and Marschke attribute the growth to increases in R&D in certain sectors as well as to increased patent yield in the computing, electronics, and auto sectors. Hall and Ziedonis study a single industry, semiconductors, where the patenting per R&D rate doubled over ten years and find that the increase is associated with the assembly of large patent portfolios in order to forestall hold-up by rivals in the industry that own patents on technology that is necessary for the manufacture of semiconductor chips. Although there is no complete agreement among these authors as to the reasons for the increase, there is some consensus that the increase in patent yield is largely concentrated in computing and electronics, which suggests either that R&D has become more "fertile" in those industries or that something else having to do with patent strategy has changed.

The growth in patenting has also renewed economists' interest in evaluating the effectiveness of the patent system in promoting innovative activity among private firms. Although evidence on the effectiveness of patents for securing the returns to innovation is mixed (see the survey evidence reported by Cohen et al 2000 and the summary of empirical work in this area in Hall 2003a), one area where patents are widely viewed as important if not essential is for securing the financing to start a new venture (e.g., see the evidence from semiconductor firms in Hall and Ziedonis 2001). The current paper probes the empirical validity of this assertion by examining the comparative market valuation of patents held by incumbent and entrant firms in the United States during the 1980s, a period in which the use of patents by U.S. firms increased very substantially, partly as a result of changes in the enforceability of patents in the courts.

As several authors have demonstrated, the creation of a centralized court of appeals specializing in patent cases in 1982, together with a few well-publicized infringement cases in the mid-1980s, have led to an increased focus on patenting by firms in industries where patents have not traditionally been

important, such as computers and electronics. In the first part of the paper I show that the decomposition of the sources of patent application growth in the United States supports the interpretation that the growth has been driven by increased patenting by U.S. firms in the electric machinery, electronics, and instrument industries, broadly defined. I also show that a time series analysis of patents reveals a very significant structural break between 1983 and 1984, one that was concentrated in the electrical sector, and more particularly, that firms in that sector (broadly defined to include electric machinery, electronics, instruments, computers, and communication equipment) increased their patenting across all technologies, accounting for essentially *all* the growth in patenting by US firms.

Using a large sample of publicly traded U.S. manufacturing firms, I then investigate how their patent valuations changed between the early and late 1980s, focusing on the differences between incumbent firms and new entrants to the industry. I am able to confirm that after the mid-1980s, patents held by entrants to the publicly traded sector are indeed more highly valued than those held by incumbents. An industry decomposition of this effect shows that it is concentrated in what Cohen, Nelson, and Walsh (2001) label complex product industries, which are industries where a single products can contain intellectual property covered by thousands of patents held by hundreds of patentholders. In such industries, patent portfolios often serve the defensive function of facilitating cross-licensing negotiations, rather than the traditional role of excluding competitors and securing the ownership of particular inventions. Although patent yield *per se* is not valued for incumbents in any of the industries, I show that in complex product industries there has been a strong positive shift in valuation for entrants as we enter the pro-patent era.

2 Changes in the U.S. patent system

A number of changes to the patent system, both legislative and via legal precedent took place during the 1980s and more recently. These changes are summarized in Table 1. A series of court decisions have expanded legitimate subject matter to include genetically-modified organisms, software, and business methods.[1] Legislative changes have enhanced the ability of patentholders to enforce their patents, both via the creation of a specialized patent court, and via various procedural changes made at the same time. The Hatch-Waxman Act made patents even more important than they had been for pharmaceutical companies seeking to block generics from entering the market, by extending the lifetime of their drug patents to compensate for delays in regulatory approval.

Table 1
Major Changes to the U.S. Patent System

Year	Event or case	Result
1980	Diamond v Chakrabarty	patentability of artificially engineered genetic organisms
1980	Bayh-Dole legislation	increase in university patenting
1981	Diamond v Diehr	patentability of software
1982	legislation	Creation of CAFC; patent validity more likely to be upheld
1984	Hatch-Waxman Act	increased importance of patents for drug firms vis a vis generic producers
1985/6	TI sues Japanese semiconductor firms	wins suits; turns to suing U.S. semiconductor firms, funding R&D from licensing royalties
1986	Kodak-Polaroid	Decision on instant camera patent; final injunction against Kodak leading to $1B judgment
1994	TRIPS agreement	harmonization drive begins
1998	State Street and ATT vs. Excel	patentability of business methods

Following these legislative changes, the demonstration effect of a series of infringement cases had a powerful effect on the thinking of some firm managers. The Kodak-Polaroid case mentioned in the table ultimately cost Kodak a billion dollar judgment and shut down their instant camera business in 1986. It also demonstrated that the ability of a patentholder to obtain an injunction against the use of the supposedly infringing technology well before damages were awarded was a powerful financial weapon, and one to be avoided even at considerable cost. Fear of this strategy appears to have been a strong motivation for increased defensive patent filings, at least in the semiconductor industry (Hall and Ziedonis 2001).

The result of all these events was a rapid increase in patent applications. In the next section of the paper I study the timing and composition of this increase in some detail.

2.1 The patent explosion

Figure 1 shows the number of applications and grants for all U.S. utility patents from 1953 to 2003. In addition it shows granted patents by application date for patents granted between January 1965 and December 2002.[2] Because of grant-application lags, the data on grants by application date are only complete through 1997. Figure 2 shows growth rates for the same data, smoothed using a moving average. Both graphs exhibit a substantial break in the mid-1980s: until then, patenting is roughly constant and after that it grows around five per cent per year. Real R&D increased only about 2.4% per year during the late 1980s so that patents taken out by U.S. inventors per R&D dollar also increased.

For further investigation, I focus on the patent grants by date of application (which is relevant date for an investigation of firm behavior and abstracts from variations in the application-grant lag). The properties of the patent application series were explored in two ways: first I tested for structural breaks both in the aggregate and by region and main technology class. Then I performed a growth accounting exercise over different 5-year subperiods to identify the sources of the growth displayed in the graphs.

Figure 1
USPTO Utility Patents 1953-2003

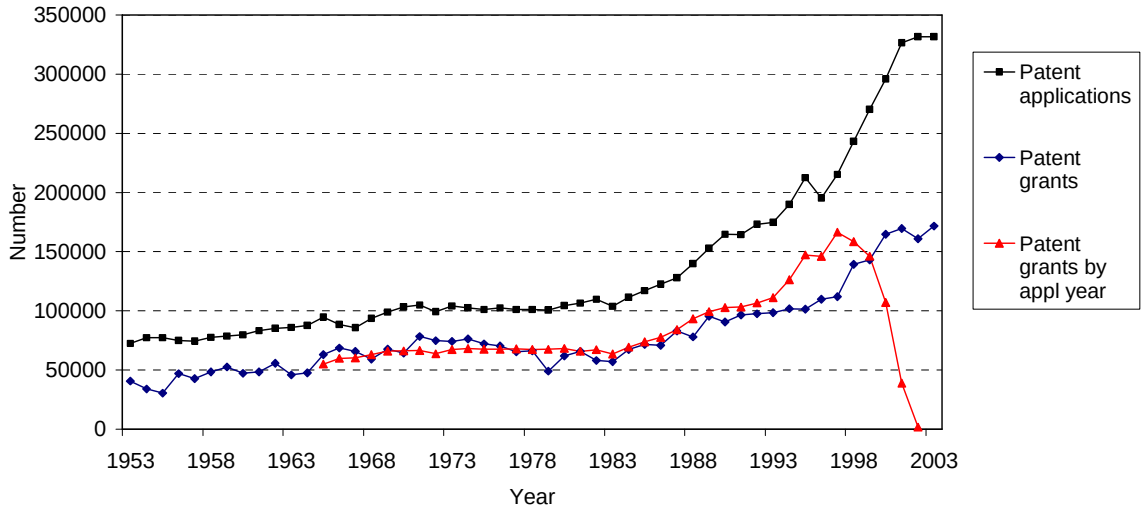
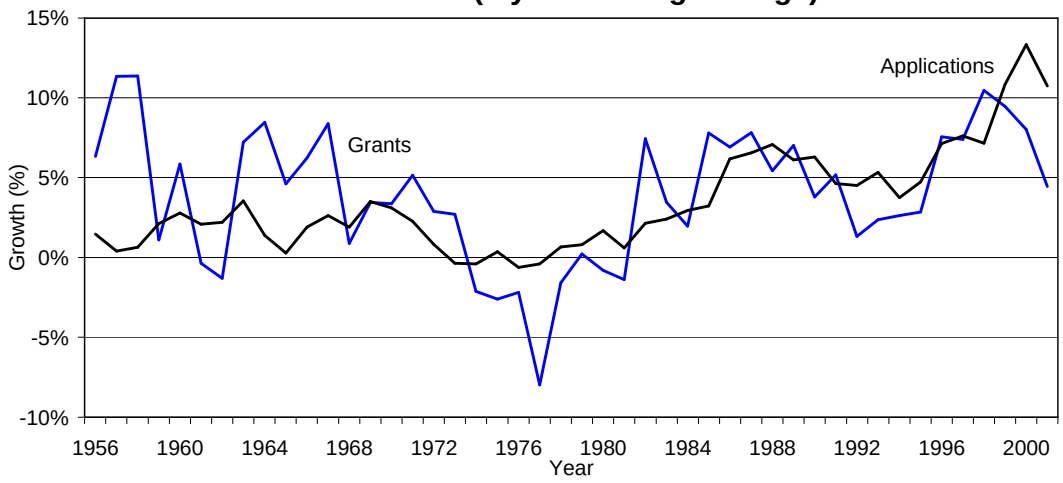


Figure 2
Growth of Aggregate US Patent Grants And Applications
1956-2001 (5-year moving average)



2.2 Tests for structural breaks

Table 2 displays the results for the aggregate patent application series. Four different versions of the series were used, two in levels and two in changes, in both cases in absolute values and in logarithms. The presence of a unit root was clearly accepted for the two series in levels, so further analysis was conducted on the differenced series. The next row of the table shows the results of a simple t-test for a change in the mean of the differenced series between 1983 and 1984 (the choice of period was based on inspection of the graph in Figure 1). Either in levels or logs, this test rejects a constant mean resoundingly. The growth rate of patent applications jumps in 1984 from an average of 0.3 per cent per annum to an average of 6.9 per cent per annum. The final rows of the table give Andrews (1993) test for a structural break of unknown date. This too is highly significant, and in the case of the logged series, the break year is identified as 1984. Therefore further analysis in this section is conducted only on the first-differenced log of patent applications.

Table 2
Tests for Unit Roots and Structural Breaks in Patent Application Series

USPTO patent applications 1967-1997 that were granted by 2002

Statistic	Patent applications	Log of patent applications	Change in patent applications	Change in logs of pat applications
Weighted symmetric unit root test	0.69	0.03	-5.08	-5.03
p-value	*0.9998*	*0.9987*	*0.0002*	*0.0002*
T-test on break between 1983 and 1984	40026 (7177)	.445 (.067)	7376 (1809)	.069 (.014)
p-value	*0.0000*	*0.0000*	*0.0000*	*0.0000*
Andrews (1993) test for unknown structural break (T=32)	86.1	126.1	21.8	23.0
p-value	*<.01*	*<.01*	*<.01*	*<.01*
Break year chosen by Andrews test	1989	1988	1993	1984

Tables 3A and 3B show the results of tests for a structural break in patent applications by region of patent application origin, and technology class. The regional breakdown reveals unambiguous evidence of a structural break for U.S. origin patents in 1984. The remaining evidence is more ambiguous: Europe and the other developing countries have a marginally significant structural break according to the Andrews test, in 1993 and 1984 respectively. Although the other regions have no identifiable break, all but the Asian-origin patents have significantly different patenting growth rates before and after 1984. The conclusion is that the highly visible increase in growth rates in 1983/1984 is primarily due to inventors resident in the U.S.

In Tables 3B and 3C, I show similar results for the six broad technology categories developed by Hall, Jaffe, and Trajtenberg 2002. Table 3B shows the tests for all patents and Table 3C for patents whose inventors were resident in the United States. The results are unambiguous: chemicals and pharmaceuticals, the industries that have traditionally identified patents as important for securing returns to innovation, exhibit little evidence of a structural break in 1984 or any other year. On the contrary, the electrical, computers and communications, mechanical and other technologies all have a significant structural break that occurs in 1984 or 1993 in the case of computers. Beginning in 1984, the growth of patent applications increased about 8-9 per cent per annum in computing and electrical technologies, and about 6 per cent per annum in mechanical and other

technologies. The next section of the paper probes the contribution of these sectors to the aggregate growth in patenting in more detail.

Table 3A
Tests for Structural Breaks by Region

Statistic	USA	Europe	Asia & Japan	Other Developed	Other
Total patents	1,499,517	533,614	461,575	71,688	6,445
T-test on break between 1983 and 1984	.084 (.018)	.037 (.019)	-.000 (.029)	.063 (.021)	.101 (.039)
p-value	*0.000*	*0.068*	*0.990*	*0.006*	*0.016*
Andrews (1993) test for structural break at unknown point (T=31)	27.14	8.93	6.84	8.86	7.23
p-value	*<.01*	*<.05*	*>.10*	*<.05*	*>.10*
Break year chosen by Andrews test	1984	1993	1972	1984	1989

Table 3B
Tests for Structural Breaks by Technology Class

Statistic	Chemical	Drugs & medicine	Computers & comm.	Electrical	Mechanical	Other
Total patents	542,700	219,257	325,665	470,463	604,679	568,489
T-test on break between 1983 and 1984	.045 (.023)	.035 (.040)	.090 (.023)	.075 (.014)	.059 (.013)	.058 (.011)
p-value	*0.041*	*0.378*	*0.001*	*0.000*	*0.000*	*0.000*
Andrews (1993) test for structural break at unknown point (T=31)	4.57	0.94	22.90	26.90	20.40	25.70
p-value	*>.10*	*>.10*	*0.0000*	*0.0000*	*0.0000*	*0.0000*
Break year chosen by Andrews test	1984	1976	1993	1984	1984	1984

Table 3C
Tests for Structural Breaks by Technology Class, US inventors only

Statistic	Chemical	Drugs & medicine	Computers & comm.	Electrical	Mechanical	Other
Total patents	292,410	128,454	162,338	243,115	315,455	357,745
T-test on break between 1983 and 1984	.049 (.024)	.06 1(.041)	.113 (.028)	.084 (.014)	.077 (.014)	.071 (.012)
p-value	*0.052*	*0.142*	*0.000*	*0.000*	*0.001*	*0.000*
Andrews (1993) test for structural break at unknown point (T=31)	5.21	2.29	32.04	37.82	29.81	33.72
p-value	*>.10*	*>.10*	*<.01*	*<.01*	*<.01*	*<.01*
Break year chosen by Andrews test	1987	1984	1987	1984	1984	1984

2.3 Accounting for patent growth

In order to carry out a simple growth accounting exercise on the patent data, I define the following:

g_t = growth of patenting from time t -1 to t
g_{it} = growth of patenting in class or region i from time t -1 to t *(1.1)*
$s_{i,t-1}$ = share of patents in class or region i at time t -1

Then the growth in patents at time t is given by

$$g_t = \sum_{i=1}^{n} s_{i,t-1} g_{it} \qquad (1.2)$$

Figures 3 to 5 show the results of the computations for three difference decompositions of the data, by major region of patent origin, and then by broad technology class and broad industry class based on the Compustat firm sample that I use later in the paper. Both of the later breakdowns are for U.S.-origin inventors only, because of the evidence that this is the source of the patent increase and because I am unable to perform an industry class decomposition on those patents (unassigned and foreign) for which I do not have ownership information. The plots in Figures 3 to 5 show $s_{it-1}\, g_{it}$ for the three different decompositions.

The figures reveal the following interesting fact: although the jump in patent applications within the U.S. occurred in all technology classes, when we look by broad industry class, we find that it occurred *only* in firms that are in the electrical, computing and instruments industries. That is, the increase in chemicals, mechanical and other technologies appears to have been driven by increasing patenting activity by firms that were not traditionally in these industries. This result is consistent with the view that there has been a major strategic shift in patenting in the electrical/computing industries, but not in other industries.

One interpretation of the contrasting findings in Figures 4 and 5 is the following: the first figure suggests an increase in innovation (as measured by patents) from the 1974-84 period to the 1984-94 period that occurred in all technology areas. But the second says that the increase was actually concentrated in firms in one sector, which implies that these firms increased their patenting not only in their own sector but in the other technology sectors

as well. This suggests that the increase is due to a strategic shift within the electrical and computing sector, rather than an increase in inventiveness across the board. Further testing of this hypothesis seems warranted to understand what the patenting behavior of the electrical/computing firms was in the chemicals/ mechanical/ other sector before and after the shift in 1984.

Figure 3
Accounting for U.S. Patent Application Growth
by Region of Inventor

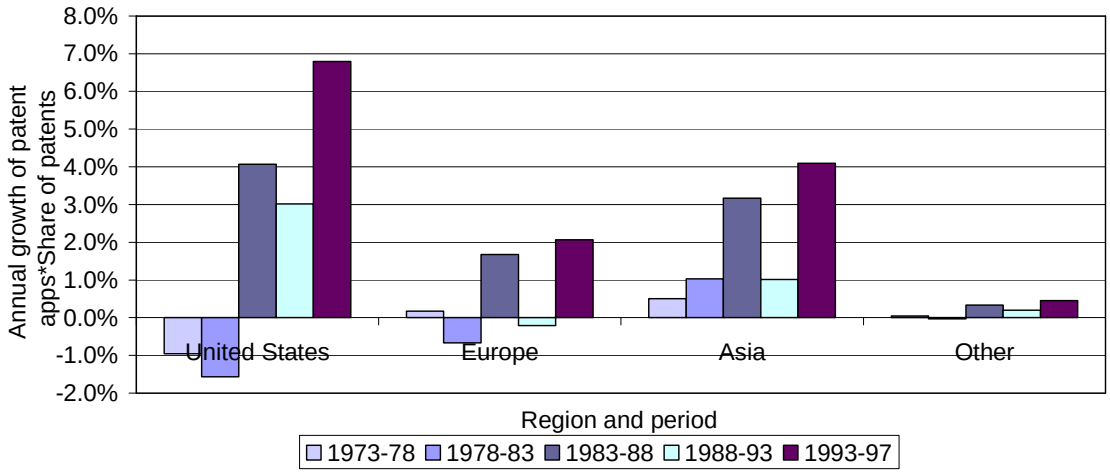


Figure 4
Accounting for U.S. Inventor Patent Application Growth
Broad Technology Class

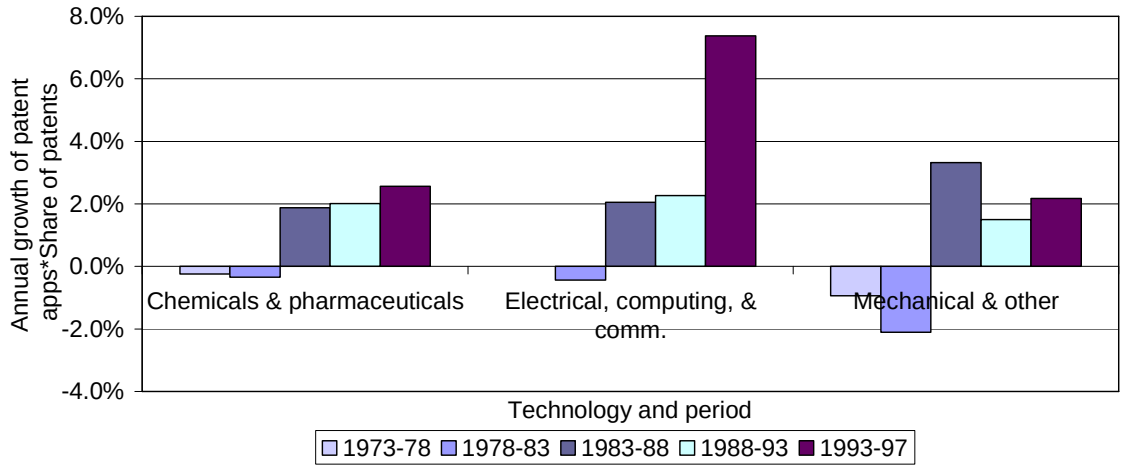
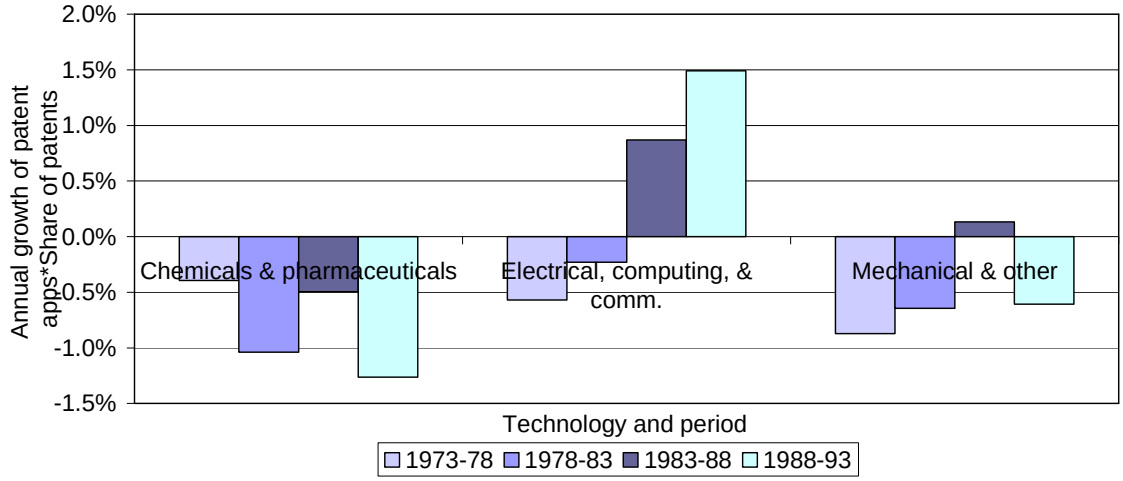


Figure 5
Accounting for U.S. Inventor Patent Application Growth
Compustat Firms - Broad Industry Class



2.4 What changed?

Given these findings with respect to timing of the surge, region of origin, and technology and industry origin, we can identify the following changes in the patent system as having provided an impetus for the increase in growth rate: the 1982 creation of CAFC and the litigation success of Texas Instruments against a number of firms in 1985/86 and Polaroid against Kodak in 1986. As a result of the creation of CAFC and as demonstrated by these cases, patents were now more likely to be upheld in litigation, and the consequences were likely to be more negative for alleged infringers, especially in complex product industries like electronic computing and communications.

In Ziedonis and Hall (2001) we reported the results of our interviews with patent counsel and CEOs at a number of semiconductor manufacturing firms.[3] The interviewees emphasized the important "demonstration effect" of Polaroid's successful patent infringement suit against Kodak; in 1985, the district court found Kodak liable for infringement and this decision was affirmed by the CAFC in 1986, barring Kodak from competing in the instant-film camera business. In 1989/1990 the damages portion of the case was tried, ultimately settling for almost one billion dollars.[4] The large penalties imposed in this case and the realization that US courts were willing to take an aggressive stance against infringement by halting—either temporarily or permanently—production utilizing infringed technologies fueled concerns among executives in

many firms, including semiconductor manufacturers, for whom it would be very costly to shut down a wafer fabricating plant for even a week.

The other widely-cited reason for intensified patenting in the industry was Texas Instruments' patent royalty strategy. During 1985-86, 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-US (Japanese) firms, TI's successful enforcement of its patents enabled the firm to charge higher royalty rates to other firms in the industry. Indeed, our interviewees were well aware of the strategies that Texas Instruments had put in place to manage—and profit from—its patent portfolio;[5] 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 during this period 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 infringe" their patents but sought royalty-bearing licenses from smaller firms more aggressively.

As Levin et al (1987) and Cohen, Nelson, and Walsh (2000) reported from their survey evidence, patents have not been considered the most important means for appropriating returns to R&D except in the pharmaceutical industry, although they are considered effective for over one third of innovations in several other industries: paper, chemicals, metal products and machinery, computers and electrical equipment, medical equipment, and autos. Cohen *et al*. probe this question further and find that when industries are divided into those producing discrete products and those producing complex products, important differences in the *reasons* for using patents emerge.[6] Industries with discrete products tend to patent for the traditional reasons of excluding competitors and preventing litigation, whereas those in complex product industries are significantly more likely to patent for cross-licensing and trading/negotiation purposes, as well as to prevent litigation.

Their evidence agrees with the Ziedonis and Hall finding that patents are now primarily used for defensive purposes in semiconductors, to protect against litigation and for cross licensing. But we also found that patents were considered important for securing financing for startups in this industry. The analysis in this section confirms that the overall surge in patenting is due to an

increased use of patents by U.S. firms in industries similar to and including semiconductors, that is, in complex product industries. The next section explores the implications of this finding for firm valuation by the market, and attempts to shed light indirectly on the financing hypothesis.

3 The market value of patents

The findings in the previous section of the paper, together with the evidence in Hall and Ziedonis (2001) and Cohen *et al.* (2000) suggest that the value of patents to the firm may differ depending on the use to which they are put. That is, if patents are primarily valued because having a large number assists in cross-licensing negotiations and serves as insurance against threats from other patentholders, the individual patents in the portfolio may not be valued separately from the fact that they are a natural consequence of the firm's R&D. That is, once we control for the level of R&D in a market value equation, there may be no additional effect arising from patenting. In particular, firms in sectors with complex product technologies should show such an effect, because in general it is the number of patents rather than the quality of each one that is relevant for defense, at least according to the Ziedonis-Hall interviewees.

At the same time, if patents help to secure financing for entry, we expect that firms who have recently entered the publicly traded sector would have a patent portfolio that is more valuable on average than that held by other firms. That is, their R&D will have been differentially successful, compared to the incumbent firms. So the hypothesis is that patents will be related to the market value of these firms, above and beyond the value from their R&D effort. In addition, I would expect this differential to be largest in complex product industries.

In this section of the paper I test these hypotheses using a simple market to book value equation at the firm level that includes the R&D assets to tangible assets ratio, the patent stock to R&D assets ratio, a dummy for firms that do not report R&D, and year dummies to account for overall market movements. The equation is estimated for two subperiods, 1980-1984 and 1985-1989, and for incumbents entrants during the two periods separately. I then go on to estimate equations separately for firms in the three different technology classes used in the previous section (electrical, chemical, and mechanical), and for the discrete product/complex product breakdown suggested by Cohen *et al.* (2000).

Finally, I use a differences in differences approach to examine whether the differential valuation of patents for entrants and incumbents in complex product industries increased relative to that for discrete product industries between the

first and the second half of the 1980s. Finding that this is so is confirmatory evidence that strategies in those industries shifted, partly as a result of changes in patent enforcement around the middle of the 1980s.

3.1 Data sample

The data sample used here is drawn from the sample described in Hall, Jaffe, and Trajtenberg (2002, 2004). It consists of about 1400 U.S. manufacturing firms with at least one patent and at least five years of data between 1980 and 1989, for a total of 9705 observations. Firms are divided into three groups: incumbents (in the sample as of 1979), entrants 1980-84, or entrants 1985-89. Note that being an entrant means that the number of shareholders in the firm was large enough for it to command sufficient investor interest to be followed by Standard and Poor's Compustat, which basically means that the firm is required to file 10-Ks to the Securities and Exchange Commission on a regular basis. It does not necessarily mean that the firm has just gone through an IPO, although for some of these firms that will be true. Most of them are listed on NASDAQ or the NYSE.

A table in Appendix A shows the industrial breakdown of these firms, and the way I classify their technologies for the tests later in this section. Not surprisingly, the industries with the highest entry rate during the period are the science-based industries in either chemical or electrical technologies: Medical Instruments, Computing Equipment, Instruments and Communication Equipment, and Pharmaceuticals. These four industries account for slightly over half of all entry during the period.

3.2 Model and estimation strategy

The model estimated is a very basic hedonic market value model, similar to that in Griliches 1981 or Hall, Jaffe, and Trajtenberg 2004. The market value of a firm is related to the book value of its assets via the following regression equation:

$$\log Q_{it} = \log\left(\frac{V_{it}}{A_{it}}\right) = \delta_t + \beta_K\left(\frac{K_{it}}{A_{it}}\right) + \beta_P\left(\frac{P_{it}}{K_{it}}\right) + \varepsilon_{it} \qquad (1.3)$$

where

V = market value of firm
A = book value of tangible assets
K = stock of R&D assets
P = stock of patents

The form of the specification is dictated by the fact that patents are roughly proportional to R&D for these firms, so that the separate impact of obtaining a patent successfully can be measured by including a patent productivity variable in the form of patents per R&D in the model. The stocks of both R&D and patents are constructed from the past R&D and patent applications history using a 15 per cent depreciation rate.

The method of estimation is ordinary least squares with standard errors robust to heteroskedasticity and serial correlation reported.[7] In estimation, the slopes and the full set of time dummies δ_t are allowed to vary across the type of firm, whether incumbent or entrant, the time period (1980-84, or 1985-89), and the technology category (in three groups, electrical, chemical, and mechanical, or two, discrete and complex).

3.3 Comparing Incumbents and Entrants

A summary of the results of these estimations is shown in Table 4, which displays the patent coefficient for all firms and for the two different industry breakdowns. Several things emerge from these tables: first, during the 1980 to 1984 period, having a higher patent productivity from R&D is not associated with an increase in market value. On the contrary, it is slightly negatively valued in electrical and chemical industries, and especially negative among entrants in the chemical sector. This latter result no doubt reflects the collapse of biotechnology valuations that occurred during this period. Except for this sector, there is no difference between incumbents and entrants in the valuation of patent per R&D yield during the first half of the 1980s.

However, during the 1985-1989 period, the patent yield of entrants in the electrical and mechanical sectors is valued at a substantial premium over incumbent firms, after controlling for their tangible and R&D assets. The difference is most stark when I distinguish between industries with discrete product technologies and those with complex product technologies. In the latter sector, having one additional patent per million dollars of R&D investment yields a market value boost of 25 per cent for newly entered firms.

Third, there is a significant difference between the two periods. In the first, patent productivity is valued negatively or not at all by the market, whether the firm is an incumbent or an entrant. In the second period, after the changes in the patent environment have taken place, patent productivity remains negative or insignificant for the value of the incumbent firms, whereas it is now significant and positive for firms in the electrical and mechanical industries; the differences are even more striking for the discrete/complex split. The last line of Table 4 shows the differences in differences estimate of the difference between incumbents and entrant firms in the two periods. The differences are most significant for the chemicals sector, where the patent valuation for entrants rose from quite negative to slightly positive, and for the complex products industry, where the patent valuation for entrants rose from zero to very positive.

Because it appears from Table 4 that the discrete/complex split is more informative for patent yield valuation than the technology split, I present the complete results for this split in Table 5, for the two periods and for the incumbent/entrant split in each, in order to look more carefully at the differences in results for the two sectors. The discrete product industries show the following pattern in both periods: first, firms that enter tend to have a substantial premium (about 100 per cent above that predicted by their assets), but R&D assets are valued less for entrants than for incumbents. At the same time, not having R&D is valued very negatively. What this suggests is that entry in this sector during the period essentially requires having R&D assets, so some of the valuation is absorbed by the entry dummy. This can occur because R&D assets are an error-ridden measure of the underlying value of the firm's knowledge base. I also note that the patent yield from these assets has no impact on firm value for firms in this sector.

Table 5
Comparing Incumbents with Entrants

Discrete Product Industries

	1980-1984						1985-1989					
	Incumbents 1979		Entrants 1980-84		Difference		Incumbents 1984		Entrants 1985-89		Difference	
Variable	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D Stock/ Assets	0.822	0.119**	0.429	0.120**	-0.394	0.169**	0.554	0.072**	0.395	0.055**	-0.160	0.090
Patent Stock/ R&D Stock	-0.025	0.014	-0.068	0.055	-0.043	0.057	-0.014	0.025	0.023	0.015	0.037	0.030
D(no R&D)	-0.012	0.039	-0.510	0.157**	-0.498	0.162**	0.016	0.045	-0.440	0.108**	-0.456	0.117**
Entrant dummy in first year			1.511	0.208**					0.802	0.203**		
Std. error; adj. R-squared	0.609		0.264				0.639		0.204			
Firms	608						568					
Observations	2622		276				2330		233			

Complex Product Industries

	1980-1984						1985-1989					
	Incumbents 1979		Entrants 1980-84		Difference		Incumbents 1984		Entrants 1985-89		Difference	
Variable	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D Stock/ Assets	0.559	0.079**	0.642	0.108**	0.084	0.133	0.251	0.042**	0.513	0.076**	0.263	0.086**
Patent Stock/ R&D Stock	-0.027	0.023	0.010	0.038	0.037	0.052	0.014	0.010	0.272	0.062**	0.258	0.063**
D(no R&D)	-0.047	0.068	-0.269	0.188	-0.222	0.200	-0.040	0.066	-0.002	0.158	0.038	0.170
Entrant dummy in first year			0.469	0.201**					0.225	0.133		
Std. error; adj. R-squared	0.676		0.203				0.621		0.176			
Firms	538						545					
Observations	2312		366				2256		284			

All equations include a full set of time dummies for each group.

Standard error estimates are robust to heteroskedasticity and first order serial correlation.

The results for the complex product industries are quite different: First, the results for the two periods are quite different, with both R&D and patent yield valued significantly more highly for entrants in the second period. During the first period, only entry itself receives a valuation premium over incumbent firms (of about 50 per cent) and not doing R&D is somewhat negative for entrants. During the second period, the value of the incumbents' R&D has fallen, whereas that for the entrants remains about the same. And as we saw earlier, there is a substantial premium for entrants that have a higher patent yield. Hall (1993) reviews the reasons for the decline in R&D valuation during this period and shows that is was concentrated in rust belt industries (e.g., metals and automobiles) and in large scale mainframe and mini computer firms, both of which were subject to restructuring during the 1980s due to the advent of the personal computer and the rise in global competition. Many of these industries are in the complex product sector.

Thus these regressions provide some support for the hypothesis that patents may serve differing functions for incumbents and entrants in complex product industries, and that this difference may have emerged in the wake of the changes to the functioning of the U.S. patent system during the early to mid-1980s. Although the division into discrete and complex product industries is admittedly rather coarse, it seems to be revealing of a considerable difference in the role of patents.

4 Conclusions

This paper has established several facts about changes in the patenting behavior of U.S. firms during the past twenty years, some more precisely and robustly than others. First, there is clear evidence of a structural shift to a higher growth rate in overall patenting in the United States between 1983 and 1984, one that is driven for the most part by U.S. firms, but with some contribution from Asia and Europe. Second, this shift is largely accounted for by firms in the electrical and computing technology sectors, although patenting by U.S. inventors has risen in all technology classes. Although R&D has also increased in this sector, this cannot explain the size of the increase in patenting. In addition, patenting per R&D dollar has actually fallen in the chemicals sector broadly defined.

These findings are subject to a couple of competing explanations: one is that of Kortum and Lerner (1998, 2003), who argue that the management of R&D has improved during the period and who find that innovative activity has risen as much as patenting, at least in the pages of the Wall street Journal. The second is that the growth in patenting is largely driven by the needs of players in complex

product industries for large patent portfolios and their consequent drive to obtain patents, even those of dubious quality, that is, even those that they have no intention of enforcing. The results thus far cannot really distinguish these two hypotheses, although we can say that if R&D management has improved, it is only in some sectors (electrical, etc.) and not in all.

The results in the second part of the paper provide some limited support for the view that that patent rights themselves are not valuable assets, once we know the amount of investment that went into obtaining the innovation, but that they may be important for new entrants. That is, a possible interpretation of these results is the following: in established firms, accumulating patents for defensive reasons has little impact on market value because the past history of R&D spending is already a good indicator of the firm's technology position. In fact, an above average accumulation of patents could be slightly negative for value if it indicates the present of threatened suits for infringement.

On the other hand, for new entrants, especially in complex product industries like electronics where patents were previously unimportant, ownership of patents may have become an important signal of viability, especially because these firms have a median intangible to tangible asset ratio of above one half. That is, as the venture capitalists argue when considering funding these firms earlier in the life cycle process, patents are essential to provide a claim on the most important asset of the firm, its knowledge capital. In the market value equation, this translates into a premium for high patent productivity, especially post-1984.

Some questions remain unanswered in this paper. First and foremost, what happened during the 1990s? Did the positive premium for entry with patents continue during the rapid growth of the computing and electronics sector in the late 1990s? Has the growth in patenting continued to be due almost entirely to U.S. firms in computing and electronics?

Notes

[1] The "extension" of patentable subject matter to business methods is of course too late to have any effect on the data considered in this paper, but it is included for the sake of completeness, and because it is in some sense a consequence of the pro-patent shift of the 1980s and the creation of the CAFC.

[2] The apparent dip and rise in applications between 1995 and 1996 is due to accelerated filing, primarily by pharmaceutical firms who wished to obtain the traditional 17 year lifetime from date of patent grant that was changed in 1996 to 20 years from date of filing. This caused a number of applications to be moved forward to the extent that was feasible. Patent applications in Hall, Jaffe, Trajtenberg technology class 31 (drugs) actually rose 45 per cent in 1995 and fell 45 per cent in 1996!

[3] The next two paragraphs are largely drawn from Ziedonis and Hall (2001).

[4] I am grateful to Cecil Quillen, who was patent counsel for Kodak during that period, for these precise recollections of the events in the case.

[5] After launching its more aggressive patent licensing strategy in 1985, TI subsequently earned almost $2 billion in royalty income during 1986-1993 (Grindley and Teece 1997).

[6] The former group includes food, textiles, paper, chemicals, drugs, metals and metal products, and the latter consists of machinery, computers, electrical equipment, electronic components, instruments, and transportation equipment.

[7] GMM in TSP 5.0 was used for estimation, in order to obtain the correct standard errors, but with instruments identical to the right hand side variables.

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Appendix A
Sector Breakdowns (number of observations 1980-1989)

	All			By Technology Base			By Product Type	
	Firms	**Entrants**	**Obs.**	**Electrical**	**Chemical**	**Mechanical**	**Discrete**	**Complex**
Food & tobacco	58	10	420		420		420	
Textiles & apparel	67	18	455			455	455	
Lumber & wood	8	0	57			57	57	
Furniture	31	5	231			231	231	
Paper	48	6	351			351	351	
Printing	27	5	218			218	218	
Chemicals	63	10	512		512		512	
Medical instruments	85	47	516	516			516	
Pharmaceuticals & soap	71	28	519		519		519	
Oil	25	3	203		203		203	
Rubber & plastics	56	13	388		388		388	
Stone, clay, and glass	24	3	163		163		163	
Primary metals	53	13	376			376	376	
Fabricated metals	85	19	543			543	543	
Machinery & engines	158	38	1,162			1,162		1,162
Computing equipment	72	39	465	465				465
Electrical machinery	90	25	642	642				642
Instruments & comm. eq.	250	104	1,716	1,716				1,716
Transportation eq.	26	2	205	205				205
Autos & auto parts	47	9	378			378		378
Misc n.e.c.	30	8	185			185		
Total	**1,374**	**405**	**9,705**	**3,544**	**2,205**	**3,956**	**4,952**	**4,568**