PATENTS, LICENSING, AND MARKET STRUCTURE IN THE CHEMICAL INDUSTRY

Ashish Arora
Heinz School of Public Policy and Management
Carnegie Mellon University, Pittsburgh, PA 15213
ashish@andrew.cmu.edu

First draft: April 1994
This version: April 1996

Many of the ideas presented in this paper are the product of an ongoing collaborative research effort with Alfonso Gambardella. I gratefully acknowledge several helpful conversations with David Hounshell, and Wes Cohen. Shane Greenstein, Nate Rosenberg, and anonymous referees of this Journal provided useful comments on earlier versions of this paper, which were presented at seminars at Wissenschaftzentrum Berlin für Sozialforschung, and Stanford University. Partial financial support from the Technology and Economic Growth project at CEPR, Stanford University is gratefully acknowledged. The customary disclaimers apply.

Abstract

The strategies of rent appropriation and market structure are inter-dependent. How firms use patents depends upon industry structure, and in turn, affects industry structure. In the early part of the history of the chemical industry, market leaders combined patents and secrecy to deter entry. Patents were also used to within cartels to organize technology licensing. The role of patents changed in the less concentrated post war markets. In bulk organic chemicals and petrochemicals, even chemical producers use licensing as an important means of generating revenue from process innovations. The increased importance of technology licensing is closely related to the emergence of a class of specialized process design and engineering firms that have played an important role in the development and diffusion of process innovations. In so doing, they have helped lower entry barriers and increase competition in the industry.

Keywords: *Patents, Licensing, Market Structure, Chemicals*

1. Introduction

Public policy analysis of patents has traditionally typically identified patents with a discrete innovation and focussed on the tradeoff between the short term restrictive effects of monopoly, and the longer term benefit of the incentives to innovate. In recent years there has been a growing recognition that this conceptualization is inadequate, for at least two reasons. First, firms invest in technological competencies and other assets that, in turn, are used to develop into innovations. Patents are only one means of protecting these technological investments, and often not the most important means of doing so.[1]

The second reason for doubting the adequacy of the traditional conceptualization is closely related to the first: knowledge itself is an important input into the production of knowledge. Therefore, knowledge flows between innovators, and between innovators and users have an important impact on the rate of technological progress. Patents affect the efficiency with which a market system accomplishes such transactions in knowledge. Put differently, the role played by patents is much broader than merely excluding competitors, and has changed in response to changes in industry

[1]The results of the well known Yale survey (Levin *et al* [1987]) suggested that for most "high tech" industries patents are less effective than alternatives such as secrecy, and sales and service effort. However, respondents from the chemical industry rated product patents as very important. In particular, while process patents were seen as ineffective in other industries, process patents in chemicals were seen as effective.

structure. How patents are used (or not used) affects the opportunities for entry, industry structure, as well as the rate of technological change itself.[2]

How does the efficacy and the role of patents change with industrial structure, and in turn, how does the changing role of patents affect industry structure? This question forms the point of departure for this essay which can be seen as an attempt to use examples from history of the chemical industry to flesh out the conjectures of the economic theory of patents. This essay will focus primarily upon organic chemicals, defined broadly to include petrochemical building blocks, synthetic fibers, plastics, and other types of chemical products based upon petrochemical feedstocks.

The next section examines the strategies of firms in the pre WW I dyestuffs industry. The market leaders - the major German dyestuff companies - skillfully combined patents with secrecy to deter entry and preserve market leadership. While patents were used to preserve the international oligopolies and cartels that characterize the industry before WW II, section 3 argues that patents were also useful for facilitating the flows of technological knowledge inside the cartels. After WW II, important sectors of the chemical industry witnessed a great deal of entry. Section 4 argues that increased licensing of process technologies played a major role in enabling new firms to enter, and in turn, entry induced existing producers to increase licensing. This section also discusses the

[2]David [1992] notes that the restrictive effects of patents on the access to information on research methods and results may impose substantial efficiency losses in addition to the static "deadweight loss" of monopoly. (See also Scotchmer [1991] for further discussion.)

emergence of specialized engineering contractors who played a distinctive role in the post war era as licensors and diffusors of technology. The next section discusses how changing competitive conditions themselves affect the incentives to license. Conclusions and implications for patent policy are contained in section 6.

2. Combining patents and secrecy to deter entry

Organic dyestuffs is one of the earliest of the science based "high tech" sectors. As many authoritative sources (e.g. Haber [1958], Haynes [1954]) have noted, patents have played a key role in organic dyestuffs, at least since the latter part of the nineteenth century. A recent account of the research organization of the German chemical industry argues that serious research in the area of organic chemistry, particularly organic dyestuffs, in German chemical firms started with the passage of the German Patent Law in 1877 that provided a common patent regime for all German states (Marsh [1994]).[3]

Having obtained an early lead in organic dyestuffs, German companies used patents systematically to exclude competitors and preserve their market position, both at home and in other countries as well. Liebenau [1992:65] states that

[3]The law is said to have prevented companies from simply copying new chemical processes, as they had done earlier. Haber [1958: 293] cites evidence that for the period 1877-1904, out of 12,128 chemical patents in Germany, 3,447 were for processes for bleaching and dyeing and 3,733 related to processes for preparing colors, lacquers and varnishes.

> "In outline, the strategy involved patenting as many potentially interesting products of industrial R&D as possible. ... Patents were taken out to build walls around whole research areas. ... This strategy was certainly recognised by the three leading German firms by the end of the 19th century. From that time, the big three, Bayer, BASF, and Hoechst owned between them 66% of all German held US chemical patents."[4]

However, the role played by know-how, usually protected by secrecy, is less well understood. Hounshell and Smith [1988: 89-90] describe how German companies skillfully combined patents and secrecy to keep potential imitators at bay in dyestuffs. The dyestuffs would be composed of a number of different compounds, the precise composition of the compound kept secret, but the individual compounds protected by patents. In other instances, dyes patents described the results of a certain process. To minimize the information disclosed, German firms issued misleading "evasion" patents. In other cases, entire groups of compounds would be patented, with only a fraction having properties similar to the dye of interest, so that a rival would have to undertake elaborate and costly experimentation to discover the actual composition of the dyestuff placed on the market. The net effect was that competitors found it very difficult establish a clear relationship between dyestuff patents and the dyestuffs sold on the markets. These so called "unclassified" dyes commanded significant price premia, often selling for 40-50% over the standard colors whose composition was known.

---

[4] IG Farben continued this strategy. In 1936, IG Farben held 4,000 patents in the US, and was receiving new ones at the rate of about 300 per year (Smith [1992: 147]).

The importance of know-how and trade secrets, and their complementarity with patents is illustrated by the history of dyestuffs in the US. During WW I, the British blockade prevented German dyestuffs from reaching the US and prompted Du Pont to enter the dyestuffs business. To this end, it entered into a collaboration with a British firm which had access to a Hoechst plant confiscated by the British government, and hired a consultant familiar with dyestuffs that BASF sold in the US. In 1919, Du Pont also managed to get access to all German patents from the Chemical Foundation Incorporated, which offered non-exclusive licenses on royalty basis on all German patents in the U.S. expropriated as a result of WW I. By this time Du Pont had already spent $11 million on strengthening its capability in the dyestuffs area (Hounshell and Smith [1988:94]). But despite all this, Du Pont also had to undertake a clandestine campaign to lure away (in violation of the trade secrecy laws) several chemists working in German companies, by offering them ten to fifteen times their German salaries. Hounshell and Smith [1988: 96] conclude that the "... recruitment of German chemists definitely aided [Du Pont's] quest to become a profitable dyestuffs manufacturer".

In analyzing the choice between patents and secrecy, the literature has largely focussed largely on the trade-off between the protection that patents provide against "reverse engineering" versus the information they disclose to potential imitators (e.g. Horstman *et al.* [1985]). An important factor affecting this trade-off is the nature of the knowledge that is sought to be patented. Knowledge based on inductive and empiricist procedures is often difficult to protect through patents. This is not only because such knowledge is often difficult to codify but also because patent claims on such knowledge would have to be narrow to be valid, but would therefore disclose a great deal to potential imitators.

The logical course of action would be to patent the clearly articulated aspects of the technology, and to keep secret the rest.

In dyestuffs, many aspects of the development of organic dyes were poorly understood. Even when the precise composition of the dye was not known, empirical techniques for production were developed through trial-and-error. The absence of a sound theoretical understanding does not preclude patenting; instead, it raised potential cost through disclosure to rivals, outweighing the benefits of patenting. Hence, not only was the composition of the dye sometimes kept secret and not patented, other characteristics of the dyestuff critical to its performance, such as the way in which the elements were ground and mixed, were often not disclosed in patents.[5]

The strategic use of patents and secrecy to deter entry into a technological area was not confined to dyestuffs. It was tried in other areas where the German companies were market leaders. The Haber-Bosch process for ammonia, a truly significant process innovation, was protected by more than 200 patents that covered the apparatus, temperatures, and pressures, but avoided particulars about the catalysts employed or their preparation. The catalyst was critical to the successful operation of the

[5]The prevailing patent law encouraged such a strategy. Early German law provided for process patents but not for product patents. Thus, there was no incentive (and indeed, a disincentive) to disclose the precise composition of the dyestuff. Moreover, in contrast to present day US patent law which requires "enabling disclosure" - disclosure that would allow one skilled in the arts to carry out the invention - the patent law on this subject appears to have been far less stringent. An interesting avenue of enquiry is the extent to which these changes were inspired by the historical experiences such as those discussed above.

process, and keeping it secret significantly increased the expense and time for firms trying to circumvent the Haber-Bosch patent (Haynes [1954: V II, 86-87]). It is important to note that the discovery and the preparation of the catalyst was overwhelmingly empiricist and inductive. By contrast, the temperature and pressure conditions were determined (by Fritz Haber) by a more deductive procedure, where the experimental work was guided by theoretical principles of thermodynamics and principles of reaction equilibrium.

3. Cartels and patent licensing

The German strategy of using patents to "build walls around entire research areas" was particularly successful when they had a substantial lead over their rivals. But over time, some firms, such as ICI, and Du Pont managed to reduce the gap, at times helped by their national governments, leading to the formation of a number of international cartels. The chemical industry was probably one of the earliest "global" industries and cartels, both domestic and international, were an important aspect of this globalization. In fact, the pre-WW II international chemical market has been characterized by many as a sort of a "gentlemen's club" (*e.g.* Spitz [1988], Smith [1992].)

While some cartels, such as the alkali cartel, were purely about market sharing, others were organized around a common technology, and were often initiated by the patent holder. The latter would license the technology, often in exchange for a small financial stake. For instance, Solvay required that the licensees of his ammonia-soda process share any improvements with him, and in turn, these were shared with other licensees. This helped the Solvay retain control, as well as enable his process to remain competitive against rivals (Haber [1958: 89], Hounshell [1992]). Although cartels had explicit market sharing rules, economic theory suggests that licensing agreements alone could have achieved many of the restrictive outcomes that the inter-firm agreements specified. Using a simple theoretical model of cournot oligopoly in the product market, one can show that a patent holder can design a licensing contract offered to all existing producers that replicates the monopoly outcome (see Katz and Shapiro [1986] for details.)[6]

These cartels used a number of instruments, including patent licensing agreements, to maintain market shares and deter entry. However, patents were more effective in deterring entry by smaller, less established firms: In some instances the innovator licensed the technology to dissuade a major competitor from litigating the patent in court. Often it was not even in the imitator's interest to have the patent invalidated because it would allow entry of other firms. With cartels, patents were licensed only to other member firms. Innovative firms would enter into cross-licensing arrangements with other firms but firms which lacked proprietary technologies could not get licenses.[7] Thus patents

---

[6]Du Pont's cellophane license to Sylvania (a US subsidiary of a Belgian company) in 1933 specified a 2% royalty on sales *up to quota* (defined initially as 20% of the market with small increases over time), and a huge 30% on sales above the quota. Thus contract implied that *de facto* (though not *de jure*) the licensee would never find it profitable to produce more than the agree upon amount. Hounshell and Smith [1988: 177] note that the quota proved to be a non-binding constraint.

[7]Writing of the last quarter of the nineteenth century, Haber [1958: 199] notes " ... (S)oon, however, the number of British patents taken out by the Germans increased, while their willingness to grant licenses decreased ... for British manufacturers made fewer discoveries of immediate commercial value and so lost business and they were also unable to secure licenses from Germans and Swiss inventors and so lost more business."

were used to prevent entry and provide stability to the existing market structure. But within the cartel, patents provided a way of organizing the purchase and sale of technology, and providing incentives for research, because compensation could be based on the patent positions.

For instance, ICI and Du Pont had a long standing agreement which involved technology licensing as well as the extensive sharing of information and know-how, which also had provisions for compensation for the technology that was transferred. This implied that even when the one company had control over the basic patents, both would have incentives to carry out further research in improving and developing the innovations. This implication is borne out by the available historical evidence, which suggests that both firms invested in research to improve their bargaining positions.[8] Hence, although ICI obtained the basic patent on polyester, Du Pont had developed significant expertise in the production process based on its experience in nylon, and controlled the melt-spinning process which was crucial for successful commercialization. The two companies settled on a cross-licensing agreement, which allowed both companies to benefit from the other's innovation.

4 The impact of licensing on market structure

One of the major impacts of WWII was to change the way in which firms used technology licensing. The increased use of licensing in the post war period is most marked in process technologies in

[8]Taylor and Sudnik [1984] quote an ICI manager as claiming that Du Pont deliberately carried out research in polyethylene process technology, on which ICI had the composition of matter patent, to gain better terms for licensing. Hounshell and Smith [1988: 200] confirm that Du Pont patented its improved lower-pressure process to this end.

refining, petrochemicals and other sectors characterized by relatively homogenous products, large markets and large scale plants. During the war, the inter-firm diffusion of technology was enhanced due to government cooperative research programs such as the synthetic rubber program in the US, as well as greater mobility of personnel. Thus some of the less prominent firms acquired significant technological capability and experience, which they exploited in the post war period when demand grew rapidly.

The post war era also witnessed the rise of a new of type of firms that specialized in the development and sale of process technologies. These specialized engineering firms, SEFs henceforth, have been important sources of process innovations. But what is more important how they appropriated the rents: Lacking the assets required to commercialize their innovations themselves, SEFs used licensing as the principal way of profiting from their innovations. In so doing, they enabled a number of firms to enter new markets, as well as changed the way in which established firms viewed technology licensing.

The rise of SEFs is closely linked to the tremendous growth in the use of oil and natural gas, instead of coal, as the basic raw material the chemical industry. As a result, many oil companies became important players in the petrochemical market. Oil companies had long paid attention to improving their processes. In contrast to chemical companies, which were very secretive about their production processes, oil companies were more open about their technical operations. Indeed, from very early in this century, oil firms used specialized sub-contractors in various capacities.[9] As these specialized engineering-construction firms (SEFs) grew in their ability to handle more sophisticated tasks, process design became a part of their activities as well.

The first SEFs were formed as early as the 1920s in the US. By the 1960s, SEFs had come to occupy an important place in the industry. In a pioneering study, Freeman noted that for the period 1960-66, " ... nearly three quarters of the major new plants were "engineered", procured and constructed by specialist plant contractors" (Freeman [1968:30]). As SEFs became important sources of plant design, their importance as sources of process innovation also increased (Mansfield *et al.* [1977]). SEFs have been particularly innovative in two areas: catalytic processes, and engineering design improvements.[10] As noted above, they have relied upon licensing to appropriate rents from their innovations. Freeman showed that for the period 1960-66, SEFs as a group accounted for about 30% of all licenses (for processes). In a more recent study, Arora and Gambardella [1992] find that for the period 1970-90, in refining and petrochemicals (defined broadly to include basic chemicals such as

[9] Oil companies perceived control over oil deposits, and distribution networks as more important strategic variables, as compared with refining technology. As one source has characterized the situation, large oil companies concentrated their energies on " ... searching for crude oil and establishing retail market facilities ... " (Landau and Brown [1965:35]).

[10] UOP, and Scientific Design - Halcon are two of the SEFs that have radical innovations to their credit. UOP has a number of catalytic refining and reforming processes which it has licensed widely. Scientific Design pioneered a number of new pathways to produce basic inputs for synthetic fibers and plastics, such as the air oxidation process for para-xylene (used for polyester). A number of other SEFs have contributed to advances in engineering design. For instance W.M. Kellogg made significant contributions to developing high-pressure processes for ammonia in the 1930s, while Badger is associated with fluidized bed catalytic processes (in collaboration with Sohio).

ammonia, plastics, and synthetic fibers) the largest 110 SEFs accounted for over half the total licenses granted.[11]

SEFs led the diffusion and spread of modern technology, first to Europe, and then world wide, to Asia, East Europe, Latin America, and the middle East. Not only did the SEFs supply technology, they also supplied know-how about design and construction of these large petrochemical plants. Petrochemical plants are very large and complex, and constructing and operating them is a challenging task. By offering a package comprising of core technology, engineering design and know-how, and contract construction services, SEFs significantly lowered entry barriers for new firms.

The implications for industrial structure have been profound.[12] Spitz [1988: 313] notes that in most major products, the number of major producers was between five and fifteen. By contrast, in the pre-

[11]All licenses are process licenses. The dataset covered the period 1980-90, and was based on data on about 10,000 plants all over the world. It should be noted that the percentage refers only to cases where we could discover the identity of the licensor. If we consider all plants, the figure drops to about 30%.

[12]In their recent work, Cohen and Klepper [1994, 1996] have explored the implications of the absence of licensing of process innovations. Their theoretical model predicts that larger firms would tend to invest more in process R&D, and therefore, would be more innovative in terms of output. In related work, Klepper [1996] extends this intuition to the analysis of industry structure. His model shows that early entrants that manage to survive and grow gain a large advantage over future entrants because the greater size of the former allows them to invest greater amounts in cost reducing process innovations. In time, future entry gets blocked because the size advantage of established firms proves overwhelming. Although first mover advantages have been substantial, both at the level of the firm as well as the product, there is evidence to the contrary as well. A prominent example is the recently

WWII era, it was unusual to have more than three producers. This is confirmed by table 1, which shows that the total number of producers in the bulk organic chemicals grew rapidly in the post war era, while the number of producers in bulk inorganic remained largely stable. The growth in the number of producers came about even though the minimum efficient scale of plants was increasing. However, it is also true that demand grew rapidly at this time. The fraction of entry that can be attributed to the increased licensing cannot be estimated precisely without more data, although there is some scattered evidence that suggests that changed licensing policies of chemical firms, partly motivated by anti-trust concerns, significantly lowered entry barriers (see for instance Backman [1964: 47-50]).

Other studies provide evidence consistent with the hypothesis that the SEFs were major suppliers of technology and know-how to new entrants. In a study of 39 commodity chemicals in the US in a period from the mid '50s to the mid '70s, Lieberman [1989] found that after controlling for demand conditions, experience accumulated by incumbents did not act to deter new entry. Given the importance of learning by doing, this suggests that entrants had access to other sources of know-how, most likely from SEFs. This interpretation is further supported by Lieberman's [1989] findings that entry into concentrated markets, which were also marked by low rates of patenting by non-producers (both foreign firms and SEFs), usually required that the entrant develop its own technology. By contrast, less concentrated markets were associated with high rates of patenting by non producers and

---

reported exit of ICI from polyethylene, and polyester fibre, products which ICI had first commercialized, and for which it was one of the leading licensors in the world.

high rates of licensing to entrants. In a related study (of a subset of 24 chemicals) Lieberman [1987] found that high rates of patenting by non producers were also associated with faster rates of decline in prices. Once again, this evidence is consistent with an interpretation where patenting by non-producers (especially SEFs) led to entry by new firms through licenses.

SEFs concentrated upon processes, rather than products. Product innovation requires close links with downstream buyers, and the technical ability and financial resources to undertake costly market development. Thus, a division of labor developed in process innovation in sectors where a separation between process and product innovation was easier - in large volume, organic intermediates. A pre-condition for such a division of labor is that process patents had to be effective, and information had to be communicated across firms at low cost. Without protection, process innovations could only be protected through secrecy. But secrecy is not a viable strategy if the objective is to license the technology: Market transactions in technology require property rights.[13] In addition to having patent protection, process technologies also had to be articulable in abstract terms, independent of the details of the particular producer or product, or else the cost of technology transfer would outweigh the value.

[13]Although trade secrets can be licensed, even such transactions are facilitated by patents. In a study not limited to the chemical industry, I find that the provision of technical know-how (in the form of technical services) in international technology licensing contracts was strongly associated with patent protection (Arora [1996]).

The development of chemical engineering played an important role in both respects. Chemical engineering developed more general and abstract ways of conceptualizing chemical processes. A chemical engineer could therefore see common elements across a number of processes which might appear very different and diverse to a chemist from an earlier generation, thereby directly reducing transaction costs of licensing technology.[14] Chemical engineering (and the concomitant developments in polymer science and surface chemistry) also provided the language for describing more precisely the innovations, as well as the scope of innovations. Greater precision in the description of the innovation allowed more effective patent protection, because pioneering patents could be broad without being invalid. As Haber [1971: 219] notes, that chemical engineering was a key factor in the licensing of technologies in high pressure synthesis, and plastics, because " ... the process details lent themselves readily to licensing... ".

5. The impact of market structure on licensing

Not only did the licensing activities of the SEFs affect market structure by inducing entry, they also had a major effect on the licensing strategies of the chemical producers themselves. In a marked departure from their pre WWII strategy of closely controlling their technology, a number of chemical

[14] Von Hippel [1990] has very interesting parallels with the ideas presented above. To use Von Hippel's terminology, more general and abstract knowledge makes specific information less "sticky", while chemical engineering made possible a partitioning of the product and process developments.

and oil companies began to use licensing as an important (although not the only) means of profiting from innovation.[15] As Spitz [1988: 318] put it

> "... some brand new technologies, developed by operating (chemical) companies, were made available for license to any and all comers. A good example is the Hercules-Distillers phenol/acetone process, which was commercialized in 1953 and forever changed the way that phenol would be produced."

The available evidence suggests that technology licensing is still quite widespread. Table 2 presents evidence for the period 1980-90 which indicates that the percentage of plants which involve an explicit reported licensing transaction varies from about 60% for petrochemicals to about 15% for pharmaceuticals. Of these reported licensing arrangements, a little over 80% involve sales of technology between firms that are not linked through ownership ties, with significant variations across different sub-sectors. Thus the data show that licensing is most common in sectors with large scale production facilities, with relatively homogenous products, and with a large number of new plants. It is less common in sectors marked by product differentiation, custom tailoring of products for customers, and small scales of production. Column C in table 2 shows that a little less than half of these reported transactions are accounted for by SEFs. Note that these data do not distinguish between product and process licenses. In sectors such as petrochemicals, and fertilizers, the vast majority of licenses are process licenses. In other sectors, such as pharmaceuticals, and organic

[15] Landau [1966:4] writing two decades after the end of the war, noted that the "... the partial breakdown of secrecy barriers in the chemical industry is increasing ... the trend toward more licensing of processes".

chemicals, the fraction of product licenses is likely to be higher. However, such sectors display lower overall rates of licensing in any case.

In other words, SEFs play a major role as licensors, but at least half the licenses sold to unaffiliated firms are by other chemical producers themselves. Some chemical companies that have been major licensors of their patented technologies include: ICI in ammonia, Union Carbide in polyethylene/polypropylene and air separation technologies, Montecatini (including affiliates such as Himont) in polypropylene, and Mitsui in polypropylene as well. Oil companies have been active in licensing their technologies. Shell, Mobil, BP, and Amoco are some of the oil companies that have actively marketed their refining and petrochemical technologies.

Table 3 shows the licensing activities of 15 of the largest chemical producers (excluding pharmaceutical firms) in the world in the previous decade. It shows that even the largest chemical firms license out their technologies, and some do so quite actively. The table shows quite clearly also that there are significant differences across companies in the extent to which they license their technology. A comparison of columns 3 and 4 shows that all companies are more likely to use licensing in dealing with overseas investments. Oil companies license more frequently than chemical companies, but there is considerable variation within the chemical companies themselves. Part of these inter firm differences reflect the differing importance of licensing across product groups (see table 2), but others reflect differences in corporate strategy, as can be seen by comparing UCC and Dow, which are substantially similar in terms of the product markets in which they operate, but differ in their propensity to license. A recent search of the trade publications turned up further anecdotal evidence that shows that at least in some markets, chemical and oil companies aggressively compete to sell technology, often in collaboration with an SEF which undertakes to provide the engineering and other know-how.[16]

The question of whether or not licensing of proprietary technology by chemical firms is a long run profit maximizing strategy has been a matter of considerable debate in the industry itself.[17] Licensing may imply increased competition and rent dissipation. In addition, transaction cost perspectives imply that contractual arrangements for the sale of technology involve inefficiencies and problems of enforcement (*e.g.* Teece [1987]), reducing the attractiveness of licensing as a means of rent appropriation. Caves *et al* [1983] find that due to imperfections in the licensing market, licensors capture only about a third of the rents from the innovation. In his remarks upon technology licensing, Arrow [1962: 355] notes that:

---

[16]For instance, Dow, a company that has a reputation of very closely holding onto its technology, has recently decided to sell licenses in the chlor-alkali area (Brooks and Watzman [1986]). Union Carbide and Himont compete with each other in selling polypropylene licenses, along with Amoco, which is a more recent entrant (Morris [1989]). BP and Du Pont compete in polyethylene process technology (Mullin [1993]). In methyl *tert* butyl ethers (MTBE), UOP, Mobil-BP, and Phillips Petroleum are amongst the competing licensors (Rotman [1993a]); in cumene, Mobil/Badger are the latest entrants in the licensing market which includes UOP, ABB Lummus Crest, and Monsanto / Kellog (Rotman [1993b]).

[17]For instance, an industry consultant criticized Union Carbide for the liberal licensing of its polypropylene/polyethylene Unipol process, claiming that licensing reduced profitability, both for the industry, and also for Union Carbide (Spalding [1986]). See also Spitz [1988] for similar views. On the other hand, in polypropylene, McMillan [1979], suggests that the licensing royalties earned by Montecatini (estimated by McMillan to be of the order of tens of millions of dollars) exceeded the profits that Montecatini earned from self production.

> One interesting feature ... is the relatively low price paid for information. Patent royalties are generally so low that the profits from exploiting one's own invention are not appreciably greater than those derived from the use of others' knowledge. It really calls for some explanation why the firm that has developed the knowledge cannot demand a greater share of the resulting profits.

How can one explain the widespread use of licensing by major chemical producers? Limited financial and managerial resources, lack of familiarity with international markets, as well as anti-trust considerations are obvious factors that would induce a firm to license. But there is a less well understood aspect that provides deeper insights into why licensing is so widespread in chemicals: Strategies of rent appropriation depend upon the existing market structure. Specifically, the presence of competing technologies drastically changes the payoff to the strategy of trying to keep one's technology in-house. For instance, suppose there are two viable processes for the production of a particular product, each owned by a different firm. Licensing imposes a negative pecuniary externality upon other incumbents, which is not taken into account by the licensor. This is because other existing producer will share the "rent dissipation" as a result of an increase in entry, but will not share in the royalty payments that the licensor will receive. In other words, firms with rival proprietary technology may find themselves in something akin to a "prisoner's dilemma" -- unless restrained by mutual agreements, they would compete not only to supply products but also to supply their technologies. Note that if one of the firms is an SEF, then the dilemma becomes more acute because the SEF can only exploit its innovation through licensing.

The intuition can be developed using the textbook example of cournot oligopoly with constant (and symmetric) marginal costs and linear demand. In the context of this familiar model of oligopoly, the opportunity cost of licensing to the licensor is related to the decrease in output and profits as a result of entry. The decrease in profits is larger, the larger is the market share. However, the decrease in the profit of the licensor is less than the profits of the entrant, as long as the licensor is not a monopolist. If the licensor shares the market with other producers, all other producers also experience a reduction in their profits as a result of the license.

The model predicts that the incentive to license to an entrant would be more higher in markets with a larger number of producers, because a potential licensor would have a lower market share on average. Further, collusion between potential licensors would be difficult to achieve for the same reason. Similarly, licensing would be more prevalent in larger markets, with more potential entrants. These predictions are consistent with Lieberman's results [1987, 1989] discussed earlier. To the extent that the number of plants is correlated with the number of producers, table 2 also bears this out.

Section 6 Summary and conclusions

The way in which patents are used has a two way relationship with the structure of the industry. The incentives to use patents to deter entry and to control the future development of the technology are high for market leaders in concentrated markets. In turn, close control over technology by incumbents raises entry barriers for potential entrants. In less concentrated markets the availability of many qualified potential licensees and the threat of competing technologies induces greater licensing.

Licensing itself reduces entry barriers and de-concentrates markets. In the chemical industry, the emergence of a group of specialized engineering contractors in the post WW II period has contributed significantly to the growth of licensing. These specialized firms competed with chemical firms in the market for process technologies, and played a major role in transferring technology across national boundaries.

This paper has argued that patents can play an important role in facilitating such flows of knowledge, and hence, in facilitating technological progress. Some authors, most notably Merges and Nelson [1990], have argued that broad patents would tend to inhibit technological progress by concentrating control over future development of a technology. But as exemplified by SEFs, and more recently, biotechnology, innovations may systematically originate in firms that will not develop and commercialize the innovations themselves. Rather, a division of labor in innovative activity can exist, whereby innovations are transferred to other firms which develop and commercialize them (Arora and Gambardella [1994]).

Patents have played a crucial role in facilitating the market in technology that underpins this division of labor. Small firms, and firms without well-established production and marketing capabilities are the ones most dependent upon licensing and hence, upon patent protection. Formally, one might say that broader patent scope has the highest marginal value for firms with very weak commercialization capability. Weak patent protection would be sufficient (though not necessary) to eliminate such firms as effective sources of technological change (e.g. Cohen and Klepper [1996]). Patents, and the strength and scope of intellectual property more generally, affect not only the incentive to invest in research, but also the incentive to organize and store the research findings in ways that are useful to other firms and researchers.[18]

For public policy, the import of these observations hinges on the answer to the following questions: From where (and what types of firms) are the initial and the subsequent innovations likely to arise? If firms with strong commercialization and development capabilities are likely to remain the main innovators even in the presence of strong patent protection, then patents will not significantly increase the incentives to invest in research. This is because large firms can appropriate the rents by a combination of secrecy, first mover advantage, and rapidly moving down the learning curve. Narrow patents may be more efficient in balancing the trade-off between competition and incentives to innovate if the potential innovators have other ways appropriating rents. By contrast, when small firms enjoy a comparative advantage in innovation, broad and vigorously protected patents may be vital, provided the underlying knowledge base is adequate for a clear articulation and codification of the new discoveries.

[18]Economic theory of innovation has implicitly assumed that all useful technological knowledge, once produced is costlessly transmittable. In the vast majority of cases, in both the chemical industry and elsewhere, this is simply untrue. Over two thirds of the British firms interviewed by Taylor and Silberston [1973] said that know-how transfer was the main (or one of the main motives) behind their patent licensing agreements. Arora [1995] shows that simple contracts can accomplish the transfer of know-how provided patent protection is strong enough.

Table 1: Number of firms producing selected chemicals in US

Products	1947	1961
Ammonia	12	42
Ethylene Glycol	4	12
Polyethylene	2	14
Xylene	12	22
Benzene	11	33
Alkalies and Chlorine	18	18[1]
Cyclical (coal tar) crudes	13	13[1]
Naphthalene	12	13
Phenol	10	9

Source: Compiled from Backman [1964], page 7, and table 4.

Notes:
1. Figure relates to 1958

Table 2: Licensing patterns in major chemical sectors, 1980-90, all countries.

	Formal License (%) A	Inter-Firm (%) B	Licenses by SEFs (%) C	Total projects D
Air Separation	52.8	77.7	77.7	602
Fertilizers	58.2	96.6	59.0	1395
Food Products	25.2	82.6	34.8	365
Gas Handling	28.5	95.2	67.3	1170
Inorganic Chemicals	41.6	78.5	34.8	1535
Industrial Gasses	57.8	91.2	55.2	536
Metals	23.9	84.7	20.3	740
Organic chemicals	36.3	57.3	17.5	1367
Organic refining	53.8	91.0	53.6	2540
Petrochemicals	57.6	83.6	40.9	3220
Pharmaceuticals	16.6	50.6	6.1	892
Plastics	51.1	63.2	12.9	2077
Paper	19.1	96.1	7.9	533
Textiles and fibers	62.3	84.6	34.4	487
Average	45.2	81.1	39.6	18748

Source: Author's calculations based on Pergamon Database

Notes:

1. Column A reports the percentage of new plants where a licensor was reported. Column B reports the percentage of reported licenses sold to firms that were unaffiliated with the licensor (not subsidiaries, no common parent). Column C reports the percentage of reported licenses sold by SEFs.
2. Sectors with fewer than 300 total plants between 1980-90 have been omitted.
3. The averages in the last row are weighted average for the entire database, including the sectors not included in the table.
4. In Air separation, and Industrial gasses, chemical companies such as UCC also build and supply plants, and were classified as SEFs for that purpose.

Table 3: Licensing Behavior of Major Chemical Companies, 1980-90, all markets

Rank	Company[1]	# of Licenses as % of total investment[2]	licenses as % of self investment	Domestic licenses as % of domestic investment
1	Bayer	21	27	14
2	BASF	20	24	8
3	Hoechst	20	25	3
4	Du Pont	16	19	6
5	Dow	5	5	4
6	ICI	3	30	12
8	UCC	44	78	40
9	Shell	32	46	18
10	Exxon	23	30	16
11	Amoco	35	53	26
14	Mobil	25	33	20
15	Air Liquide	21	27	9
16	Monsanto	41	71	32
17	Montedison	45	83	32
18	Enichem	8	8	0
	Average[3]	27	37	16

Source: Author's calculations based on Pergamon Database

Notes:

1. The companies are listed in order of chemical sales (based on Fred Aftalian, A History of the International Chemical Industry, University of Pennsylvania Press, 1991, Philadelphia, Appendix). I have omitted Allied Signal, Ciba-Geigy, Merck, and Proctor & Gamble, because they had very few plants listed in the database.
2. Total investment - total number of new plants which were licensed by the company plus total number of new plants of the company in the period 1980-90.
   Self Investment - total number of new plants of the company in the period 1980-90.
   Domestic licenses - number of new plants which were licensed in its domestic market by the company.
   Domestic investments - total number of new plants between 1980-90 of the licensor company in its domestic market.

3. This is a weighted (by the number of new plants) average. The values are essentially unchanged even if one excludes the three oil companies - Mobil, Exxon, and Amoco.

Arora, A., 1995, "Licensing tacit knowledge: Intellectual property rights and the market for know-how", The Economics of Innovation and New Technology, Vol 4., 41-59.

Arora, A., 1996, "Contracting for Tacit Knowledge: The Provision of Technical Services in Technology Licensing Contracts", Journal of Development Economics, Vol 50., No. 2.

Arora, A., and Gambardella, G., 1994, "The changing technology of technological change: General and abstract knowledge and the division of innovative labour", Research Policy, 23, 1994, 523-532.

Arora, A., and Gambardella, G., 1992, "The division of labour in the international market for petrochemical plant", unpublished manuscript, Carnegie Mellon University.

Arrow, K.J., 1962, "Comments on case studies", in R.R.Nelson (ed.) The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton, NJ, Princeton University Press.

Backman, J., 1964, Competition in the Chemical Industry, Manufacturing Chemists' Association, Washington DC.

Brooks, K., and Watzman, A., 1986. "New entries vie in chlorine technology" Chemical Week, Vol.139, No.7, 22-23, Aug 13.

Cohen, W., and Klepper, S., 1992, "The anatomy of industry R&D intensity distributions", American Economic Review, Vol. 82, No.4, 773-799.

Cohen, W., and Klepper, S., 1996, "A reprise of size and R&D", Economic Journal, forthcoming.

David, P.A., 1992, "Intellectual property institutions and the panda's thumb: Patents, copyrights, and trade secrets in economic theory and history", *Working paper #287*, CEPR, Stanford, CA.

Freeman, C., 1968, "Chemical Process Plant: Innovation and the World Market", National Institute Economic Review, No.45 (August), 29-51.

Haber, L.F., 1958, The Chemical Industry During the Nineteenth Century, Clarendon Press, Oxford.

Haber, L.F., 1971, The Chemical Industry: 1900-1930, Clarendon Press, Oxford.

Haynes, W., 1954, American Chemical Industry, volumes 1-6, Van Nostrand, New York.

Hounshell, D.A., and Smith, J.K., 1988, Science and Strategy: Du Pont R&D, 1902-1980, Cambridge University Press.

Hounshell, D.A., 1992, "Managing industrial research and development in an era of globalization: Some implications from the chemical industry", *unpublished paper*, Department of History, Carnegie Mellon University.

Katz, M.L., and Shapiro, C., 1986, "How to license intangible property", Quarterly Journal of Economics, pp. 567-589.

Klepper, S., 1996, "Entry, exit, and innovation over the product life cycle", American Economic Review, forthcoming.

Landau, R. and Rosenberg, N., 1992, "Successful commercialization in the chemical process industries", in Rosenberg *et al* (eds.) Technology and the Wealth of Nations, Stanford University Press, Stanford, CA.

Landau, R. and Brown, D., 1965, "Making Research Pay", AIChE-I. Chem. E. Symposium Series No.7, London Institute of Chemical Engineers, London, pp.7:35-7:43.

Leaversuch, R., 1992, "Technology Agreement Hastens Resins Development", Modern Plastics, Vol.69, No.6, 26, June.

Levin, R.C., *et al.*, 1987, "Appropriating the returns from industrial R&D", Brookings Papers on Economic Activity, Vol 14, pp. 551-61.

Liebenau, J., 1992, "The management of high technology: The use of information in the German chemical industry, 1890-1930", in International Cartels in Business History, Kudo, A, and Hara, T., (eds.), University of Tokyo Press, Tokyo.

Lieberman, M., 1987, "Patents, Learning by Doing, and Market Structure in the Chemical Processing Industries", International Journal of Industrial Organization, Vol.5, pp.257-276.

Lieberman, M., 1989, "The learning curve, technological barriers to entry, and competitive survival in the chemical processing industries" Strategic Management Journal, vol.10

Mansfield, E. et al., 1977, The Production and Application of New Industrial Technology, Norton & Company, New York.

Marsh, U., 1994, "Strategies for success: Research organisations in German chemical companies and IG Farben until 1936", History and Technology, v. 12, no. 1.

McMillan, F., 1979, Chain Straightners, Macmillan Press, London and New York.

Merges, R., and Nelson, R., 1993, "On limiting or encouraging rivalry in technical progress: The effect of patent scope decisions", *unpublished paper*, Columbia University.

Merges, R., and Nelson, R., 1990, "On the complex economics of patent scope", Columbia Law Review, Vol.90, No.4, 839-916.

Morris, G.D.L., 1989, "The PP License Battle", Chemical Week, Vol.144, No.24,18, Jun 14.

Mullin, R., 1993, "Process technology: Business holds steady", Chemical Week, vol.152, No.1, 46-47, Jan 6/13.

Reader, W.J., 1970, 1975, Imperial Chemical Industries, a History, 2 volumes, Oxford University Press, London.

Rotman, D., 1993a, "Race to license new MTBE and tame routes heats up", Chemical Week, vol.152,No.1, 48-49, Jan 6/13.

Rotman, D., 1993b, "Mobil/Badger to market zeolite-based cumene technology", Chemical Week, Vol.152, No.7, page 9, Feb 24.

Scotchmer, S., 1991, "Standing on the shoulders of giants: Cumulative research and patent law", Journal of Economic Perspectives, Vol.5, No. 1, 29-41.

Smith, J.K., 1992, "National goals, industry structure, and corporate strategies: Chemical cartels between the wars" in International Cartels in Business History, Kudo, A, and Hara, T., (eds.), University of Tokyo Press, Tokyo.

Spalding, B.J., 1986, "Is It Smart to License Out Technology?" Chemical Week, Vol.138, No.15, 30-31, Apr 9.

Spitz, P.H., 1988, Petrochemicals: The Rise of an Industry, John Wiley, New York.

Stokes, R., 1988, Divide and Prosper: The Heirs of IG Farben under Allied Authority 1945-51, University of California Press, Berkeley and London.

Taylor, G.D., and Sudnik, P.E., 1984, Du Pont and the International Chemical Industry, G.K.Hall and Co, Boston, MA.

Taylor, C.A., and Silberston, Z.A., 1973, The economic impact of the patent system: A study of the British experience, University of Cambridge, D.A.E. *monograph* 23, Cambridge, CUP.

Teece, D.J., 1988, "Technological Change and the Nature of the Firm", in Dosi *et al* (eds.), Technological Change and Economic Theory, 1988, Pinter Publishers, London.

Travis, A.S., 1993, The Rainbow Makers: The Origins of the Synthetic Dyestuffs Industry in Western Europe, Associated University Presses, London.

Von Hippel, E., 1990, "Task partitioning: An innovation process variable", Research Policy, 19, 407-418.