MARKETS FOR TECHNOLOGY AND THEIR IMPLICATIONS FOR CORPORATE STRATEGY

by

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January, 2000

Abstract

Although market transactions for technologies, ideas, knowledge or information are limited by several well known imperfections, there is increasing evidence that, during the last two decades or so, such market transactions have become more common than in the past. These markets bring about new challenges to the firms. This paper examines some implications of markets for technology for the firms' corporate and technology strategies. Markets for technology change the traditional mindset in which the only available option for a company wishing to introduce an innovation is to develop the technology in-house, or for a company developing the technology to own the downstream assets needed to manufacture and commercialize the goods. This affects the role of companies both as technology users (they can now "buy" technologies) and as technology suppliers (they can now "sell" technologies). The implications for management include more proactive management of intellectual property, greater attention to external monitoring of technologies, and organizational changes to support technology licensing, joint-ventures and acquisition of external technology. For entrepreneurial startups, markets for technology make a focused business model more attractive. At the industry level, markets for technology may lower barriers to entry and increase competition, with obvious implications for the firms' broader strategy as well.

Key words: markets for technology, intellectual property, technology strategy

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1. INTRODUCTION

The German chemical companies are thought to have pioneered the institutionalization of in-house R&D early in the 20th century, an organizational innovation that was rapidly adopted by leading firms in technology based industries all over the world. This model of organizing innovation, where R&D and the complementary assets required for innovation are largely integrated inside the firm, has prevailed ever since. Indeed, it has been held up as a part of the recipe for lasting commercial success (e.g. Chandler, 1990). The theoretical underpinnings of this model have been examined by several authors. For instance, Nelson and Winter (1982) argue that the development of technology and innovations is based on organizational routines which are difficult to transfer across organizational boundaries. Relatedly, Teece (1988) has highlighted the transaction costs involved in transferring knowledge and technological information through arm's length market-mediated contracts.

However, in the past two decades or so, there has been a rapid growth in a variety of arrangements for the exchange of technologies or technological services, ranging from R&D joint ventures and partnerships, to licensing and cross-licensing agreements, to contract R&D. Although we lack comprehensive empirical measures over time, all the available evidence suggests that the trade in technologies has become more common than in the past. Recent studies have documented an increase in licensing revenues earned by US firms (Dengan, 1998) and the upsurge in patenting activities, possibly reflecting the increased opportunities for technology licensing (e.g. Kortum and Lerner, 1999; and Hall and Ham, 1999). Teece himself has recently noted that, under certain conditions, trade in technologies is possible and likely (e.g. Teece, 1998; and Grindley and Teece, 1997). In short, markets for technology are emerging and developing in several high-tech industries.

This paper is part of a larger project on the nature and functioning of markets for technology, and their implications for economic and business policy. (See Arora, Fosfuri and Gambardella, 2000.) In this paper we examine what the growth of markets for technology implies for corporate strategy. Markets for technology affect the role of companies both as technology users (they can now "buy" technologies) and as technology suppliers (they can now "sell" technologies). Markets for technology change the traditional mindset in which the only available option for a company wishing to introduce an innovation is to develop the technology in-house, or for a company developing the technology to own the downstream assets needed to manufacture and commercialize the goods. Entrepreneurial startups may be able to focus more narrowly than in the past on developing technology rather than on its application, by relying on licensing and other arrangements to appropriate the returns to their innovative efforts.

Moreover, markets for technology can undermine privileged access to technology that incumbent firms in an industry may enjoy, because competitors and entrants may acquire the technology from alternative sources of supply in the market. At an industry level, markets for technology lower entry barriers and increase competition, compress product lifecycles: all changes which require appropriate strategic responses.

We begin the next section by clarifying what we mean for markets for technology and by briefly reviewing some evidence on the rise of such markets in recent years. Section 3 analyzes the consequences of "missing" markets for intangible assets, and how the behavior of companies can be affected once markets for such assets arise. Section 4 focuses on large, established firms. We discuss how some of the established technology leaders are modifying their strategies for appropriating rents from innovation by incorporating technology licensing as an important option. Section 5 examines the different challenges faced by the smaller firms, especially technology-based startups. Sections 6 deals with the external acquisition of technology. Section 7 discusses the implications on entry and competition. Section 8 summarizes our main conclusions.

2. MARKETS FOR TECHNOLOGY

2.1 A tentative definition

In this paper we use the term “market” in a broad sense. Strictly speaking, market transactions are arm’s length, anonymous, and typically involve an exchange of a good for money. Many, if not most, transactions for technology which we have observed in recent years, would fail one or the other criterion. Often they involve quite detailed contracts and may be embedded in technological alliances of some sort.

This ambiguity in the way technology is transacted is linked to the inherent peculiar nature of technology as an economic asset, and as a potential object of exchange. Technology typically comes in very different forms, and no general definition will fit. For instance, technology can take the form of “intellectual property” (patents) or intangibles (e.g. a software program, or a design), or it can be embodied in a product (e.g. a prototype, or a device like a chip designed to perform certain operations), or it can take the form of technical services. We will not attempt to define technology, treating it instead as an imprecise term for useful knowledge rooted in engineering and scientific disciplines, which usually also draws from practical experience from production. In turn, this means that technology transactions can take different forms, from pure licensing of well defined intellectual property, to complicated collaborative agreements which may well include the further development of the technology, or its realization "from scratch".[1]

The US Dept. of Justice provides a useful definition of markets for technology in its *Antitrust Guidelines for the Licensing of Intellectual Property* (US Dept. of Justice, 1995). Markets for technology are markets for "intellectual property that is licensed and its close substitutes – that is the technologies or goods that are close enough substitutes significantly to constrain the exercise of market power with respect to the intellectual property that is licensed." (US Dept. of Justice, 1995: 6.) Our definition also encompasses what the Dept. of Justice calls markets for innovation, which include arrangements in which the parties involved agree to conduct activities, jointly or independently, leading to future developments of technologies that will be exchanged (or jointly owned) among them. This is typically the market for contract R&D and certain technological alliances and joint-ventures.

In sum, a market for technology refers to transactions for the use, diffusion and creation of technology. This includes transactions involving full technology packages (patents and other intellectual property and know-how) and patent licensing. It also includes transactions involving knowledge that is not patentable or not patented (e.g. software, or the many non-patented designs and innovations).

[1] Transactions in technology can also occur through mergers and acquisitions, and through the mobility of people. However, given the already very broad scope of this paper, we shall ignore these cases here.

2.2 Some suggestive evidence

Markets for technology are not a new phenomenon. Lamoreaux and Sokoloff (1997; and 1998) have documented the existence of an active market for patents in the US during the 19th century. However, it appears that these markets declined after the 1920s, and have become reinvigorated only in the last couple of decades.[2] In a companion paper, we provide rough aggregate estimates of the size and scope of markets for technology for recent decades. Using systematic data on technology transactions we found that the extent of technology trade has grown in the 1990s, and high-tech industries like software, chemicals, and electronics lead the growth of such markets (Arora, Fosfuri and Gambardella, 2000).

Specific industry case-studies provide possibly the most compelling evidence of the increasing importance of technology markets. The chemical industry for instance is one in which technology licensing, both products and processes, has been quite widespread for many years. (See Arora and Gambardella, 1998; and Arora and Fosfuri, 2000.) Similarly, technology trade is becoming fairly extensive in leading high-tech industries such as software, semiconductors, and biotechnology. In semiconductors there has been a significant growth of the so-called "fabless" or even "chipless" companies, which specialize in the design of self-contained, independent chip "modules" and sell their designs to other companies that design and manufacture the complex chip in which the individual modules are embedded (Linden and Somaya, 1999). Further evidence about technology trade in semiconductor is provided by Hall and Ham (1999), who find that licensing and cross-licensing deals have risen significantly

[2] A study by the British Technology Group (BTG, 1998) has concluded that most large firms in the industrialized countries have unused technologies that they have not licensed in the past but would like to do so. This points to the under-development, if not absence, of a market for technology. Supporting evidence comes from an estimate by the European Union that, in Europe, 20 billion dollars are spent every year to develop

in this industry and that the propensity to patent has increased during the last decade in response to the greater need to protect intellectual property in such deals. (See also Grindley and Teece, 1997.)

3. MARKETS FOR TECHNOLOGY AND CORPORATE STRATEGIES

3.1 The effects of "missing" markets for corporate assets

In order to understand the implications of markets for technology for corporate strategy, it is useful to begin with a more general discussion of missing markets for assets that distinguish a firm from its competitors. Porter (1985; and 1990) argues that competitive advantage arises when the firm can find ways for differentiating from its competitors. To do so, the firm has to have access to assets that its competitors cannot access. These assets include technology, production expertise and facilities, strong brand names, and established marketing channels. Many of these assets cannot be easily bought and sold – markets for these assets may not exist.[3]

What are the consequences of such a missing market? The immediate consequence is that the innovator must exploit the technology in-house. That is, in order to extract the value from the asset, the asset (or rather its services) must be embodied in goods and services and sold. Such goods and services must have lower costs or command higher prices, to deliver

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innovations and technologies that have already been developed elsewhere. (See *www.european-patent-office.org/patinfopro/index.htm.)*

[3] Clearly, assets that differentiate a firm from its competitors are different from standard commodities and so also are the markets for such assets. This is particularly true for intangible assets like technology. For one, the value of such assets is driven mostly by their use value (rather than cost of production) and will therefore depend on the prospective buyer. Furthermore, intangible assets are not easy to define and delineate. This implies that the assets may be "lumpy" – their transfer might be an all or nothing deal. In renting such assets, their use is likely to be more difficult to monitor and meter (Teece, 1998). Thus, instead of speaking of the absence of markets for assets, it is perhaps more accurate and realistic to speak about the efficiency of such markets and the costs of transacting in the market. The terminology of missing markets should therefore be understood as an expositional device.

returns that are greater than the competitive rate of return – firms employing such assets earns "quasi-rents".

Consider a case where a firm has developed a new cost reducing technology for the production of a certain good. In order to extract value from the technology, the firm must use it to produce the good. Not only does this require the firm to have access to the complementary factors (such as land and physical equipment, marketing channels and so on), but the returns would also depend on the volume of output that the firm can produce and sell. If these complementary factors are themselves not traded in a competitive market, or if firms differ in their access to them, then firms that have superior access to these complementary capabilities will be able to derive greater value from the asset. Similarly, firms that can exploit the technology on a bigger scale will be able to derive greater value. Following this logic further, larger firms or firms with superior access to complementary capabilities will have a greater incentive to invest in the technology in the first instance. Taking this one step further, firms investing in technology would be well advised to also invest in the complementary capabilities that cannot be easily and efficiently acquired from the market. In other words, as Teece (1986) put it, firms have to invest in creating co-specialized assets to maximize their returns from developing new technology.

In sum, absent a market for an asset, a firm must often acquire other, complementary, assets in order to extract profits from the asset. Thus, large, well capitalized and integrated firms have greater incentives to invest in developing new technologies (Nelson, 1959). Conversely, smaller firms face major hurdles in developing and commercializing technology.

The situation is quite different when the asset can be sold or rented. The importance of complementary assets is greatly diminished. A market for the asset provides the innovator – a firm that has developed new technology – with more options. Instead of embodying a newly developed technology in goods and services, a firm may choose to sell or license it to others. This does not mean that innovating firms should become pure licensing companies, although several small (and not so small) firms have nevertheless been (and are) very successful as specialized technology suppliers. Rather, as we shall see below, the appropriate strategy in the presence of markets for technology depends on the efficiency of markets for other types of assets, including finance. Moreover, in thinking about how a market for technology conditions strategies, there is one other industry level force that must be considered. Markets, particularly efficient markets, are great levelers. A market for technology lowers entry barriers and increases competition in the product market, which often implies a rethink of existing strategies.

3.2 Market for technology and strategies for appropriating rents

Teece (1986) identifies several critical dimensions for the appropriability of the returns of firm's intellectual property: nature of technology, strength of property rights regime, complementary assets, ease of replication and ease of imitation. Appropriation through licensing works best when there exists a substantial gap between replication and imitation costs. If the technology is easy to replicate and transfer but difficult to imitate, the innovator can capture a large part of the rents simply by licensing. Hence, when the underlying knowledge base is sufficiently codified and no context specific, and intellectual property rights are well defined and protected, licensing can work well.

For instance, as discussed in Arora and Gambardella (1998), there exists a very large market for chemical processes and engineering services. The development of chemical engineering played an important role in developing more general and abstract ways of conceptualizing chemical processes. As well, patents are thought to work better in chemicals than in other industries (see for instance Levin et al., 1987; Cohen et. al., 1997). In addition, many processes, especially in petrochemicals, are designed around a specific variety of catalyst which can be kept proprietary because of the difficulty of imitation from simple structural analysis alone. The licensor can therefore use the catalyst as a credible hostage: failure by the licensee to respect the initial agreement can trigger a cutoff in the supply of the catalyst.

However, Teece (1988) argued that the appropriation of the returns from innovation through licensing is the exception and not the rule. In other words, the best way of appropriating the rents from technology is by directly embodying it into goods and products. In a more recent paper, Teece (1998) recognizes that the formation of markets for technology might significantly change this view. He notes that the unbundling of intellectual property from products generates a new environment for knowledge management where the focus is on how to capture value from knowledge assets. Teece still believes, however, that "...becoming a pure licensing company not directly involved in the production market and increasingly remote from the manufacture and design of the product itself can be a risky strategy...". (See Grindley and Teece, 1997.) This is probably correct. Nonetheless, under some conditions, the risk is worth the additional reward. Moreover, a market for technology gives an innovator more options. The innovator can evaluate whether it is the best placed to extract value from the asset by embodying it in products and services. This must be balanced against the transaction costs involved in trading the technology. Licensing is an important option, not mutually exclusive with own production. Hence, with a market for technology, a firm clearly needs to recognize what its core, non-tradable and tradable competencies are. Having done so, it can then decide whether a given discovery or technological competency is to be exploited in-house or through licensing. In many instances, firms might possess some "non-core" technologies (in some cases, of very substantial value) which need to be licensed.

The decision on whether to exploit in-house or not depends on a number of factors. First and foremost, it depends on the distribution of complementary assets. If the firm has superior access to the complementary assets compared to its rivals, in-house exploitation is clearly an attractive strategy. Conversely, if the firm lacks the complementary assets, it may consider selling or licensing the technology. An important special case arises when the asset in question is generic in terms of its application, such as the case of a general purpose technology. In this case, only an extraordinarily large and well diversified firm will be able to satisfactorily exploit the technology in-house. Instead, it is far more likely that the relevant complementary assets will be more broadly distributed, so that licensing the technology broadly would yield higher returns.

The foregoing highlights the importance of the transaction costs involved in the markets for different types of assets. If the transaction cost of acquiring complementary assets such as production and marketing capabilities are lower than the transaction costs involved in selling or licensing the technology, an innovator lacking the complementary capabilities may nonetheless choose to exploit its technology in-house. In fact, there are clearly many factors that affect transaction costs for technology exchange. Foremost among them are well defined and enforced property rights. Property rights are easier to define and enforce, and transaction costs for technology licensing contracts are lower when the knowledge is articulable (Winter, 1987), and can be represented in terms of general and abstract categories (Arora and Gambardella, 1994). Such representations reduce the context dependence of the technology, freeing it up to be used more generally and reducing the cognitive barriers to technology transfer. (See also Von Hippel, 1990 and 1994.)

The decision about in-house exploitation also depends on the extent of competition in the different markets. For instance, the innovator may face much greater competition in the product market than in the market for technology. In this case, the returns from in-house exploitation are likely to be small, limited by the ability of the innovator to increase its sales and gain market share, which is typically a slow process. The innovator may face much less competition in the technology market, and may be able to extract much higher returns there. These considerations lead Qualcomm to exit from producing handsets embodying its CDMA technology and focus on technology licensing. About ten years ago, Qualcomm introduced a wireless telephone technology, based on CDMA technology (Code Division Multiple Access) which was markedly superior to the existing technology. It embodied this technology into cellular phones (handsets) and grew rapidly, with a turnover of $4 billion, and a net income of more than $200 million in 1999. However Qualcomm has decided to drastically refashion its business. Citing falling margins in the CDMA handset operations, it divested itself of manufacturing and focus on generating and licensing its CDMA technology. As Irwin Jacobs, chairman and CEO, says "..We'll let others deal with wrapping plastic around chips...". (*Business Week*, 1999, Dec 6: 96-98) On an annualized basis, Qualcomm earned nearly $400 million in licensing and royalty in 1999, which is slightly more than what Qualcomm spent on R&D in the same year (Company 8-K report, 1999).

4. LICENSING AND RELATED TECHNOLOGY STRATEGIES BY LARGE FIRMS

4.1 Revenue vs. rent-dissipation effects in the licensing strategies of the large firms

As discussed in Arora and Fosfuri (1999), the decision by a firm of whether or not to license is the result of two main forces pushing in opposite directions: the "revenue effect" and the "profit dissipation effect". In this respect, licensing raises a trade off. The licensing and royalty revenues net of transaction costs (the "revenue effect") have to be balanced against the lower price cost margins and reduced market share that the increased competition (the "profit dissipation effect") from the licensee implies. Although the licensor has many different strategies to limit the extent of this latter effect (for instance, the contract might impose quantity restrictions or exclusive territories, unit royalties might be fixed such as to control the licensee's output), an entrant is nevertheless a potential threat to the licensor's market share. This implies that firms with a large market share in the product market (and by implication, possessing the required complementary capabilities) are better off exploiting the technology in-house. On the other hand, if the market share is small, the firm may be able to increase profits by licensing in addition to in-house exploitation. Similarly, licensing is more attractive when the licensee operates in a different market and is unlikely to compete very strongly.

This is exemplified by the different ways in which BP Chemicals has approached acetic acid and polyethylene. In acetic acid, BP Chemicals has strong proprietary technology and a substantial market share. It licenses very selectively, typically only licensing to get access to markets it would otherwise be unable to enter. By contrast, in polyethylene, BP's market share is small. Although it has good proprietary technology as well, there are a dozen other sources of technology for making polyethylene. Thus, BP has licensed its polyethylene technology very aggressively, competing with Union Carbide which was the market leader in licensing polyethylene technology. Even here, BP initially tried not to license in Western Europe, where it had a substantial share of polyethylene capacity. However, other licensors continued to supply technology to firms that wished to produce polyethylene in Western Europe, with the result that BP found that it was losing potential licensing revenues without any benefits in the form of restraining entry.

BP is not alone in choosing to appropriate rents by licensing its technology. A number of other firms, including companies such as Dow chemicals, DuPont and Monsanto, which have traditionally neither licensed their technology nor acquired technologies from the outside, have embraced technology licensing as an integral part of their technology management strategy. (See below.)

The recognition of the potential of the licensing market has been prompted by several related factors. First, the growing demand for technologies has increased the opportunities for selling technologies. Moreover, globalization, along with the low transportation costs of technologies, has meant that large companies with sizable technological portfolios, have the potential to exploit their technology on a very large scale, provided they license. Second, the better functioning and the increasingly better organization of markets for technology, has eased the opportunities for this type of trading. As a result, several leading large companies have recognized the opportunities for incrementing their returns on R&D by selling out technologies rather than focusing only on their internal exploitation. Moreover, as noted earlier, there is a huge potential for this strategy, as corporations have a large share of technologies that they do not use themselves. In turn, this has prompted many of these companies to organize their technological portfolios, and to focus more forcefully on the effective management of their technologies and intellectual capital.

This is reflected in specific examples of the move towards licensing by large companies given in the appendix. Clearly, there are many reasons why firms license. Firms may license to create demand, to deter entry by stronger rivals or to dissuade rivals from launching their own R&D projects in the area. Most importantly, in certain sectors like electronics and software, firms may license their technology to create *de facto* market standards which they control and can exploit. However, the examples listed in the appendix illustrate the growing importance of markets for technology. They show that large firms are actually refocusing their overall business strategy to account for the increasing importance of markets for technology.

4.2 Increasing importance of "intellectual property" management

The discussion above also points to the need for firms to take the management of their intellectual property seriously. Grindley and Teece (1997) note that in some firms the management of intellectual property has moved from the licensing of "non-core" technologies to become a central element in technology strategy. They recognize that, in industries like semiconductors and electronics, licensing and cross-licensing have become an important means for generating revenues in alternative to direct production. In turn, this implies that the management needs to undertake a more active and positive stance towards licensing and intellectual property in general. A related implication is that firms should be more careful about managing efficiently their intellectual property. In particular they should identify technological areas to apply more forcefully for patent protection. Since both applying and maintaining a patent can be costly, firms might be selective in their patenting strategy.

A recent report by ETAN (European Technology Assessment Network, 1999) on IPRs highlights several new implications that the rise in technology transactions has meant for corporate strategy. The report recognizes upfront that markets for technologies, ideas, knowledge and information, have difficulties in operating. However, it points that a well-defined system of protection of intellectual property can help developing a market for technological knowledge. The report stresses the important of IPRs proactive management both for large and small firms. The creation of an "intellectual property culture" in firms has become crucial, and this is specially true for European firms, which are lagging behind their US and Japanese counterparts.[4]

Firms are still experimenting with how best to manage their intellectual assets and no single organization scheme will suit all firms. However, what is clear is that the old system of leaving patenting and licensing decisions largely under the control of the general counsel's office is likely to change drastically.

For instance, Xerox is often seen as an example of a firm that has mismanaged its intellectual property, having invented but failed to profit from a number of pathbreaking developments such as the PC and the graphical user interface. The new CEO of Xerox, Rich Thoman, has clearly focused on IP management as a top priority. In 1997 Xerox had 8,000 patents, earning only $8.5 million in revenues, not covering even the maintenance costs. Xerox set in motion a systematic process for cataloguing and evaluating its patent portfolio, pruning and giving away (often to universities) patents it did not wish to keep, and monitoring the use of the rest. To guide the use of intellectual property, a Xerox Intellectual Property Office, XIPO was also set up as a separate profit center headed by a vice president level officer, reporting directly to the top management of the firm and oversees all patent and licensing decisions. Lucent has adopted a similar structure, creating an intellectual property business unit as a profit center, responsible for managing intellectual property on a corporate wide level (Rivette and Kline, 1999).

[4] The ETAN report also argues that a less well-understood role of patents is information sources. Indeed, although not yet routinely exploited (with the exception of chemicals and pharmaceuticals), patent databases enable access to one of the most comprehensive and accessible sources of scientific and technological information. In addition, with the new information and communication technologies this rich source of data becomes more easy to be utilized by companies and an useful instrument for designing technology strategies. A couple of recent books (Grandstrand, 1999; Rivette and Kline, 1999) lay out in more detail how patent data can be used for competitive intelligence, to identify potential licensees, to identify potential research staff as well as to understand where the firm should focus its research efforts.

Dow Chemicals has taken a somewhat different approach. Dow used to have 2 people to manage its licensing business. Individual business units made their own decisions, independently of each other. The recession in the early 1990s, and the need to cut costs brought the over $1 billion R&D budget under close scrutiny. In 1994, Dow Chemicals significantly restructured the management of its intellectual property. Each of the 29,000 patents was valued and assigned to one of 15 major business units. A new structure was put in place under which intellectual property managers from each business unit would meet regularly to review patent activity on an enterprise wide basis. Dow Chemicals now earns $125 million in patent licensing, up from $25 million in 1994 (Rivette and Kline, 1999).

4.4 Corporate Venturing

Before we move onto the analysis of technology strategies by smaller firms and start-ups, a final important technology strategy by the larger firms is corporate venturing. As Levinthal and March (1993) note, large firms, with their established routines and structures are better suited for exploitation than exploration. In somewhat different language, large firms may be better adapted to incremental improvements of existing technologies and for commercialization of discoveries than for making new discoveries, particularly radical breakthroughs. Indeed, when such firms make a significant discovery, they may not recognize or nurture it adequately, especially if the discovery is not perceived as relating to the firm's core operations and markets. Increasingly, firms are spinning off these technologies as new ventures. These ventures are initially funded and managed by the parent.

Corporate venturing has increased in popularity in recent years and some believe that it may overtake venture capital as the leading source of funding for technology based startups. Chesbrough (1999) discusses the advantages of corporate venturing compared with venture capital. The advantages include the ability to provide more "patient" capital; the disadvantages include the delays in decision making and the less high powered incentives given to managers. Many firms see this as a way of earning high financial returns as well as accomplish strategic objectives. A full discussion of corporate venturing is beyond the scope of this paper. Nonetheless, it does appear that corporate venturing may be an uneasy compromise between in-house development and an entrepreneurial startup. Corporate venturing probably works best when there are strong strategic links between the venture and the parent (Chesbrough, 1999).

5. THE DIFFERENT CHALLENGES FACED BY THE SMALLER FIRMS

Smaller firms face a different set of tradeoffs compared with leading corporations in choosing between licensing and self-exploitation. Typically, small firms, and particularly the technology-based startups, have to acquire the complementary assets should they choose to exploit their innovation by commercializing it themselves. For startups the choice often amounts to a fundamental choice of the business model itself.[5] The choice depends not only on the efficiency of a market for technology (should one exist) but also on the efficiency of the markets for the complementary assets. In other words, in deciding how to exploit their technology, small firms and startups must trade off the costs of acquiring capital and building

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[5] Although many startups adopt a business model where they begin by licensing technology and doing contract research for others and using those earnings to acquire the required complementary assets.

in-house production, distribution and marketing capability against the rents that would be lost or shared with their partners in a licensing deal.

A commonplace about technology licensing, particularly from the perspective of small firms, is that the technology owner does not get the full return from the technology (e.g. Caves et al., 1983). There are two main reasons for the failure of innovators to capture more fully the rents from innovation: inefficiency of contracts for technology and differences in bargaining power. A related potential problem is that with a royalty based contract, the innovator's earnings depend on the effort and investment that its licensees make in commercializing the technology. Thus the firm is unable to control its own fate, increasing the chances of failure. For instance, Rambus, which has developed a highly successful architectural interface that speeds up data transfer, depends critically upon manufacturers of semiconductor devices, notably Intel, for its survival.[6] In many instances, this leads entrepreneurs adopt a strategy where they try to acquire the complementary capabilities themselves to avoid having to share rents.

There are some potential pitfalls in such a strategy. The obvious one is that small firms also have limited bargaining power when it comes to acquiring capital required to build or acquire the complementary assets they need to exploit the technology themselves. Further, to the extent that many of the complementary assets are themselves not readily accessible through a market mechanism, and to the extent that the entrepreneurial start up may not be

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[6] Rambus licenses its technology to all firms that make microprocessors, DRAMS, ASICS, or PC controllers and chip sets. Rambus does not itself produce any semiconductor devices. It lacks any special advantage in the manufacture of semiconductor devices, which requires large investments in fabrication facilities in addition to a great deal of tacit knowledge. By not producing any semiconductor device, Rambus also steers clear of any potential conflict of interests and avoids competing with its customers.

very efficient at building those assets in-house, in-house exploitation is probably a much riskier and possibly less efficient strategy.

As with the market for technology, the markets for the other assets are also developing. The clearest example is the tremendous growth in angel and venture capital. As well, the great success that small startups have had in attracting financing through the equity market has reduced the cost of both technology development as well as the cost of acquiring some of the complementary capabilities.[7] Another example is the growth of merchant fabricators in semiconductors, such as TSCM and several such firms, which are developing for instance in countries like Taiwan. These firms have invested in large semiconductor foundries, manufacture application-specific integrated circuits (ASICs) and other types of semiconductor devices for other firms. A startup firm that has developed new semiconductor technology can outsource production to a foundry, and market its devices itself by developing a marketing and distribution organization. Whether it ought to develop a marketing organization or appropriate the rents from its technology through licensing the technology to others depends in part on whether it is likely to be able to develop and manage a marketing operation efficiently.

As the case of Cambridge Display Technologies (CDT) indicates, an innovative startup firm may often not be able to do so. CDT, a Cambridge University spin-off in Britain, specializes in conjugated polymer technologies, with light-emitting polymers being a key application. This can lead to the production of light-emitting plastics, for application in a

[7] For instance, Amazon, the online bookseller, is now investing large sums in building warehouses and distribution centers. An alternative strategy could have been to ally with a firm with large distribution network, such as Walmart.

wide range of businesses, from calculator, cellular phones and similar displays, to laptop computer screens.

When the technology was first developed in the early 1990s, the CTD founders, mainly Cambridge University researchers, tried to develop and manufacture the technology. The result was that the company nearly went bankrupt. When professional managers were brought in, they changed the business model so that the key CTD business is to license the technology to established manufacturers. CDT has entered into licensing and co-development and manufacturing deals with companies like Philips Electronics, Seiko-Epson, Hoechst, and DuPont. This recognizes that although CDT has world leading ability in the light emitting polymers area, it does not have the developed manufacturing and marketing skills which are also essential to be a world class display manufacturer. Through licensing out patents and performing technology transfer, CDT can enable its partners to apply their complementary skills to the technology to develop specific products for their markets.

There are other important considerations involved that militate against self exploitation as well. Even if the firm can develop and manage the complementary assets efficiently, these assets may be much longer lived than the technology itself. This puts the innovator in the position of having to develop new technologies to "feed" these complementary assets. Failing which, the firm will be left with underutilized manufacturing facilities or marketing network. Unless these assets, or their services, can be traded on the market, at least a part of the value of these assets will be lost.

The case of Syntex, discussed below, clearly illustrates the risk involved when an innovative firm chooses to build up firm specific complementary assets to exploit an innovation in-house. Syntex was founded in 1944 in Mexico City and relocated 20 years later to Palo Alto, California. During the early 1980s, the firm becomes extremely successful thanks to a non-steroidal anti-inflammatory drug based on the compound naproxen, Naprosyn, first marketed in 1976. In 1981 Syntex listed on the New York Stock Exchange and in 1987 it reached $1 billion in annual sales. However, when the patents on Naprosyn expired in 1993 and generic products start to flood the market, Syntex became financially distressed. Its stock price plummeted from $54 a share in January 1992 to $18 a share 18 months later. In late 1993, Roche Holding, the Swiss pharmaceutical firm, acquired Syntex in a deal valued more than $5 billion. Syntex's operations in Palo Alto, after some restructuring, were transformed into a research facility with support and strategic marketing planning staff.

The proximate cause of Syntex' failure was its inability to discover a new blockbuster, when the patents on Naprosyn expired. Indeed, Syntex's strong research abilities notwithstanding, pharmaceutical innovations still depend a great deal upon serendipity. Bad luck associated with large fixed costs took Syntex into a huge financial distress which triggered the acquisition by Roche.

Leaving aside the question of whether Syntex's research productivity had declined, consider the role of the business model. Had Syntex not built up a substantial downstream manufacturing and marketing capability, it might have been able to ride out the lean periods, because it would not have to find the revenues to support its downstream operations. Moreover, this business model also implied that Syntex had to invest in the extremely costly drug development and clinical trials to find its potential blockbuster drugs. The problem is not that Syntex had to exit the market. Had Syntex failed because its research ceased to be productive, exit would be both privately and socially desirable. Syntex's research capability continued to be valuable, as evidenced by how Roche repositioned Syntex after the acquisition. In sum, the problem was that Syntex failed as a pharmaceutical firm, destroying some of the value of the downstream assets that it had invested in. Put differently, even if integration did not hurt its research productivity, the failure of research destroyed the value of the Syntex brand name plus the value (partially) of other firm specific assets that Syntex had built up.

Finally, and perhaps most important from a long run perspective, integration may reduce the innovative potential of the firm, because the acquisition of the complementary assets inevitably increases the size of firms and induces important changes in the culture of the firm and in the speed and fluidity of information flows. As Levinthal and March (1993) note, organizations divide attention and resources between two broad groups of activities. They engage in the pursuit of new knowledge, exploration, and in the use and development of what is known, exploitation. Although not identical, exploration is similar to the notion of research and development, while exploitation is closer to the more downstream activities of production and marketing. A blend of exploration and exploitation is desirable (March, 1991; Levinthal and March, 1993) but dynamics within organizations may lead exploitation to drive out exploration. For instance, learning processes driven by experience, as is typically the case in manufacturing and marketing, tend to favor exploitation, because exploitation provides clearer, earlier and closer feedback (Levinthal and March, 1993).

These dynamics are hard to resist in larger organizations. Large organizations are unable to provide high-powered incentives for exploration. Contrast that with the incentives that the threat of bankruptcy and stock options provide for exploration in small startups. Further, as Stiglitz and Weiss (1981) have demonstrated limited liability implies that smaller organizations, with fewer fixed assets at stake, will be willing to undertake more risks. Large organizations can try to encourage exploration by forming and nurturing small sub-units that are isolated from the rest of the organization. As we noted earlier, such "corporate ventures" have inherent limitations and as Levinthal and March (1993) note, tend to yield modest returns at best. In sum, there are reasons to believe that as a research intensive company converts itself into an integrated firm, with in-house manufacturing and marketing units, its research productivity is likely to decline.[8]

6. THE EXTERNAL ACQUISITION OF TECHNOLOGY AND THE "NOT-INVENTED-HERE" SYNDROME

Markets for technology also affect a firm in its role as a user of technology. The objective is not only to maximize the revenues from the firm's actual stock of technologies, but also to identify technologies that are available at a reasonable price and that will increase the value of existing assets. This does not imply that firms can simply rely on outside technologies and need not invest in R&D itself. Evaluating technologies and being able to use them requires substantial in-house scientific and technological expertise (Arora and Gambardella, 1994; Cohen and Levinthal, 1989). As Mowery (1984) has pointed out, a firm is far better

[8] As against this, as Kline and Rosernberg (1986) explain in their chain-link model of innovation, these assets may also provide valuable feedback to research about customer preferences and manufacturing trade-offs, thereby making the research process economically more valuable. The chain-link model seems to be a very good model for understanding the great success Japanese firms such as Toyota and Sony have enjoyed. Nonetheless, there is a definite opportunity cost to such a tight coupling between the various parts of the innovation chain, in the form of greater emphasis to exploitation at the cost of exploration.

equipped to absorb the output of external R&D if it is also performing some amount of R&D internally. A related but different interpretation of this is provided by Gans and Stern (1997) who argue that technology buyers need to invest in R&D to strengthen their bargaining position in licensing negotiations. In short, internal and external R&D are complements, not substitutes.

The ability of the firm to evaluate and use outside technology may be conditioned by its existing organizational structure, which limits information flows, and how opportunities are framed (e.g. Henderson and Clark, 1990.) Sometimes, firms tend to disregard external technology options completely. The "not-invented-here" syndrome often has legitimate roots, as corporations attempt to instill pride in the achievements of their researchers. It may also serve to motivate the firm's researchers. Rotemberg and Saloner (1994) develop a model in which a "not-invented-here" type of corporate culture may serve a valuable role of committing the corporation to develop the technologies invented by the firm's in-house R&D departments, thereby providing the appropriate incentives to the researchers. However, in a world where R&D capabilities are widely diffused, such a commitment device is likely to be very costly.

Markets for technology increase the penalty of the "not-invented-here" syndrome. In the first place, the wide diffusion of new technology producers (other firms, smaller technology suppliers, universities, etc.) makes R&D duplications likely. Even in a specialized field, several research units may be working on similar problems, or there could be units that have already solved problems that other units are facing. By relying only on internally developed solutions, companies can end up “reinventing the wheel”.[9]

This also points to the importance of systematic monitoring of external technological developments on a worldwide basis. By using and building upon basic or generic technologies developed elsewhere, companies can focus on developing specialized applications that better suit the needs of their local markets. “Global” markets for technology can then improve the innovation potential and the competitiveness of companies in technologically and possibly economically less dynamic contexts. They can create an effective division of labor between technology producers located in areas that are more efficient in the production of technology, and local producers which have greater comparative advantages in understanding the needs of their customers. Thus chemical producers in developing countries can rely upon firms in developed countries to provide both technology and know-how, and focus on ways to source raw materials and on developing the market for the products.

This is particularly true with general-purpose technologies (GPTs) and when there exists a market for these technologies. Under such conditions, it pays the individual firms to buy the GPT, and focus on the customization of the technology, rather than developing the whole technology or innovation from scratch. For instance, firms in developing countries can specialize in adapting the GPT to their markets, and therefore rely on their non-tradable

[9] To provide some anecdotal evidence, one of us participated in 1998 in a Commission for the evaluation of R&D projects submitted for government support funding in Italy. Most of the projects were submitted by large Italian companies, or consortia of firms and other institutions. Even though the government program did require a state of the art report for the proposed technology to be enclosed with the application, most projects charged costs for internal R&D activities that involved several early steps before the development of the ultimate technology. Few projects mentioned costs for acquiring externally developed technologies (e.g. licensing costs) which their innovation could build upon. A casual search from existing patent databases revealed that in a number of cases the applicants could have exploited existing technologies to build their innovation, or at least they could have found specialist individuals or institutions that could potentially offer valuable technical consultancy services in the specific domain of their project.

knowledge of local demand, norms, and regulations. A similar argument can be made across industries rather than across countries. Notably, it pays firms to use GPTs from leading GPT industries, and customize them for their own sectors, markets or clients, rather than developing their own industry-specific technology.

To summarize, there are at least two main implications of markets for technology for companies as users (rather than producers) of technology. First, markets for technology point to the growing importance of strategies based on monitoring external technological developments. As argued by Cohen and Levinthal (1989), this also means that companies have to develop adequate internal technological capabilities because greater internal technological skills are typically associated with greater ability to take advantage from outside technological developments. Second, markets for technology can make it more efficient to "customize" products and technologies. Thus, if basic technologies can be made available to a larger number of competitors in an industry, the sources of competitive advantages move downstream. This explains why several companies are increasing the "service-content" of their products. Services, bundled with products, can be thought of as solutions to problems that customers have, rather in the way systems integrators like IBM or Anderson Consulting provide solutions to business problems rather than selling computers or software.

7. ENTRY AND COMPETITION

One obvious consequence is that markets for technology lower barriers to entry and therefore increase competition for incumbent firms. The story of the SEFs (specialized engineering firms) in chemical processing is a natural example. (See Arora and Gambardella, 1998.) SEFs are firms specialized in the design, engineering, and construction of chemical plants. Although some of them were founded as early as the 1920s, SEFs arose in the aftermath of WWII following the rapid growth of demand for chemical products. SEFs reaped the advantages of specialization. By working for many clients, they benefited from learning by doing, and by selling repeatedly their expertise (through licenses or engineering services) they could spread the cost of accumulating that expertise over a larger output. Chemical producers were also willing to employ specialist firms which would provide improved processes and cost efficient plants.

SEFs originated as an American phenomenon. However, during the 1950s and the 1960s US SEFs became a source of technology for the European and Japanese chemical industry, and later, SEFs from all the advanced countries supplied chemical process technologies to the producers in the less advanced countries. This enabled the European and Japanese chemical industry, and the chemical industry of the less developed countries later on, to rise and grow. Notice that when these companies moved overseas the fixed costs of developing the SEF technologies were largely sunk, and, as a result, the cost of acquiring technology was therefore lower than it would have been if the local companies had to develop it from scratch.

The story of the SEFs points to another implication of markets for technology. The rise of technology suppliers in one country, possibly stimulated by the domestic downstream industry, can increase the competitiveness of foreign rivals to the very same downstream manufacturers in that country. The US SEFs, spurred by the US chemical and oil industries, encouraged the competitiveness of European and Japanese chemical and petrochemical producers in the 1950s and the 1960s, which vied with the US companies in their own domestic markets, and in the international market later on. At present, chemical and petrochemical companies from the developing countries compete in their own markets with the Western manufacturers largely thanks to Western technologies. Simply put, in the international context, markets for technology can lead to a dramatic shortening of the product life cycles.[10]

The pattern is similar in several high-tech industries today. The origins of biotechnology were largely in the US, and still today the vast majority of small high-tech intensive biotech concerns is in the US. The US biotech industry is feeding the US pharmaceutical and agrochemical companies with several new products. However, their services and technology are also available to European and Japanese companies, which have entered into a number of licensing agreements and other types of alliances with US biotech firms. It may even be argued that the services available from US biotech firms discouraged the European and Japanese large companies to promote a biotech industry in their own countries. But the fixed cost of creating the US biotech industry was largely borne in the US. Similarly, large companies in Europe and Japan, as well as companies from the developing countries, are taking advantage of US technological developments in industries like software or semiconductors, which are largely created by US specialized technology suppliers.

The market for chemical process technologies has meant that chemical process technology was no longer a key strategic advantage of the established firms. The point is not that chemical process technology and technological superiority in chemical processing are

[10] This is reflected in the "crisis" that the chemical industries of the advanced industrial countries, and the far reaching consolidation and restructuring that has gone on since the 1980s.

unimportant. Indeed, technologically less sophisticated chemical companies (such as those in the developing countries) were likely to be less effective in taking advantage of the SEF technologies, and gaps between technologically advanced and less advanced firms (or countries) hardly disappeared. However, the presence of the SEFs meant that this gap was reduced, and the entry by newcomer chemical firms with no significant technological expertise became possible. Thus many firms have exited products which they innovated and in which they have had a great deal of experience in production.[11]

The point is that markets for technology, by lowering entry barriers are likely to intensify competition. This implies that firms have to cut costs, possibly by exiting businesses in which they lack a clear source of advantage. Firms also have to look for distinctive competitive assets other than technology, since often technology will cease to be a source of distinctive advantage.[12] This is for instance why detailed knowledge of the specificities of demand can become increasingly important. In turn, this means that companies should focus on knowledge and information about the local geographic markets in which they operate, or about the peculiar and diverse demands of their clients and users. And they have to make significant investments in capturing information about customer needs or the special requirements of their local markets.

The heterogeneity of demand is a potential source of distinctive capabilities. In the first place, demand heterogeneity implies that companies can extract greater value from their

[11] Thus for instance, ICI, which first commercialized polyethylene and polyester, has virtually exited from these markets (Arora and Gambardella, 1998).

[12] For example, since the 1950s the chemical companies have paid significant attention to product differentiation by developing a range of different grades of their materials to suit the specific requirements of different markets or users. Similarly, control of the production of basic feedstock, through direct investments in oil producing countries, has been for many years a relatively more important source of competitive advantages than technology for the leading oil and petrochemical manufacturers.

customers by specifying products or services that better suit their special requirements. At the same time, customers are often unable to articulate their needs in ways that can be readily transferred to the producing firms. As a result, this information can only be acquired through close relationships with them. Put simply, while knowledge about basic technologies could circulate to a greater extent, the tacit component of the knowledge bases in industry may shift towards information and expertise about what the individual customers want. This information is less tradable, and therefore it is likely to become a prominent source of competitive advantages. In short, with markets for technology, companies could take advantage of the lower cost of acquiring technologies, and focus on the combination of internal and external technologies to provide distinct solutions to their markets, customers and users. This has to be based on solid understanding of their needs, along with substantial investments in relationships with their customers and markets.[13]

The dynamic response rests on the recognition that in a rapidly moving environment, any sort of competitive advantage or distinctive ability of the company is unlikely to persist for a long time. Thus, firms have to learn how to manage themselves in an environment in which the rate of innovation is high, competition is more intense, time to market new products has to be shorter. Dynamic competitive advantages imply that companies have to learn how to re-organize themselves rapidly, and continuously deploy new competitive advantages and distinctive assets. Specifically, as markets for technology develop, technological superiority is increasingly going to be meaningless if intended as a long-term advantage from controlling a given set of technologies. By contrast, it can become a critical source of distinctive assets if

[13] Porter (1998) argues that, apart from the customers, companies should make substantial investments in developing tight linkages with the wide set of resources and infrastructures of the individual regions in which

the company is capable of cumulating technological capabilities in a certain domain, and develop continuously new technologies in that field by building on cumulative expertise in that area. Moreover, markets for technology could further enhance the returns on these capabilities, as companies may become leading suppliers in these markets as well.

Finally, we like to point out that the rise of markets for technology is not an inexorable trend but rather is historically contingent. The evidence from Lamareux and Sokoloff discussed in section 2 pointed to the flourishing market for patent licenses in America the later 19^{th} and early 20^{th} century. This appears to be one of the many points of similarity between the end of the 19^{th} century and the end of the 20^{th} century. However, by the mid 1920s, in-house R&D was beginning its rise to prominence as the dominant mode for organizing research, not challenged till the rise of the biotech companies in the 1980s. Similarly, with the exception of petrochemicals, in-house exploitation of technology was the norm till the 1990s. It is conceivable therefore that in the future, the importance of markets for technology may wane again as the technological and policy environment changes. Firms must be aware that the organizational structures they put in place to deal with the growing markets for technology may be unsuited for the future.

8. CONCLUSIONS

There is growing evidence that trade in technology has become an important phenomenon in recent years. This paper has analyzed how markets for technology affect the technology strategies of the leading companies, which can now sell technologies that they do not use in-house, thereby increasing their potential returns to R&D. For small firms and technology-based startups, markets for technology increase the effectiveness of strategies based on the specialization of such firms in technology development.

Since markets for technology involve firms as technology "buyers", it follows that the growth of markets for technology increases the importance of external monitoring of technological developments, and increases the penalty of insularity and the "not-invented-here" syndrome. Finally, markets for technology can reduce the relative importance of technology as a source of distinctive advantage, because the advantage of possessing some critical knowledge or technologies may be limited by the ability of competitors to acquire the technology from other sources. The natural consequence is that companies have to focus on other internal assets that may provide them with distinctive advantages. Detailed knowledge and information about the idiosyncratic needs and characteristics of specific markets and buyers is one of the most obvious candidates. Thus, markets for technology may actually increase the importance of downstream strategies for differentiation.

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APPENDIX:
Examples of Changed Licensing Strategies in Companies

DuPont is a good example of a large established firm that has substantially changed its attitude towards technology licensing.[14] In 1994 the company has created the Corporate Technology Transfer Group, a division with the specific task of overseeing all technology transfer activities. Reversing its tradition of treating in-house technology as the jewel of the crown, DuPont has started to exploit it through an aggressive licensing program. Starting from 1999, this is expected to be a $100 million per year business.

Indeed, many of the technologies that are underutilized in DuPont or do not fit within the company's overall business strategy are now on sale. In 1998, there were 18,000 active patents at DuPont, but only 6,000 were used to run the enterprise. On its own web page, DuPont advertises the technologies available for licensing in several areas including fibers, composites, chemical science and catalysis, analytical, environmental, electronics, and biological. In addition, in 1999 DuPont has financially backed, along with other founding members (3M, AlliedSignal, Boeing, Dow Chemical, Ford, Honeywell, Polaroid, Procter & Gamble, Rockwell) the creation of *yet2.com*, an on-line market which should allow members to buy, sell, license, exchange, and research technologies.

Not only the attitude toward selling technologies has changed, DuPont has also reversed its historical reliance on internal resources alone for the development of the technology. Indeed, by strategically leveraging its resources with those of universities, government laboratories, and other companies, DuPont hopes to lower costs, speed developments, gain access to new ideas, and ultimately strengthen the company overall position.

IBM has a long tradition of licensing and cross-licensing its technology, both as a means of accessing external technology and to earn revenues. This tradition dates back to 1956 when an agreement with US anti-trust authorities required IBM to grant non-exclusive, non-transferable, world-wide licenses for any or all of its patents at reasonable royalties to any applicant – provided the applicant also offered to cross-license its patents to IBM on similar terms (see Grindley and Teece, 1997). Although the consent decree is no longer in force, IBM has pursued a very active approach to licensing over the past decade. IBM patent licensing revenues went from $30 million in 1990 to $1 billion in 1998, or nearly $750,000 per patent, accounting for over 10% of IBM's net profits. To create such profits, it is estimated that IBM would have to sell $20 billion in goods and services.

Recently, two very large technology agreements have attracted attention and points to the revenue-generating potential of its huge in-house stock of technologies. The first deal was with Dell, a $16 billion seven-year contract which allowed the PC maker to have access to a

[14] "...For a long time, the belief about intellectual property at DuPont was that patents were for defensive purposes only. Patents and related know-how should not be sold, and licensing was a drain on internal resources ... Our businesses are gradually becoming more comfortable with the idea that all intellectual property ... is licensable for the right price in the right situation. Rather than let it sit on the shelf, we can take advantage of these underutilized assets and turn them into enormous value for the company... Appropriate licensing of our intellectual property can be seen as just one more opportunity to keep DuPont competitive and to generate value for our shareholders from the assets we own..." (Jack Krol, president and CEO, 1997 Corporate Technology Transfer Meeting).

broad range of microelectronics, networking and computer display technologies. The second, a $3 billion five-year contract with its rival EMC covered storage systems.

IBM is also actively advertising the availability for licensing of its unmatched portfolio of storage technology and patents (see the company's web page reported in box 1). Technologies available for licensing include patents in the areas of magnetic disk storage, magnetic tape storage and optical storage, storage libraries and storage subsystems. This constitutes a complete range of innovative storage technology for the personal/handheld, mobile, desktop, workstation, and server environments.

Boeing's core business includes the development and production of commercial and tactical aircraft, missiles and space systems for the US Government. However, some technologies and processes that Boeing develops do not fit with its traditional products. Some of these technologies are now available for licensing for the first time (see Boeing's web page in box 1). The set of patents and technologies available is quite large, including algorithms, laser technology, factory hand tools, measurement systems, video display, fiber optic sensors, among the others.

Philips holds a significant number of patents on various optical recording systems. Many of these technologies are now offered on sale through licensing. Licensing seems to be motivated by the need to recoup the research, development and other efforts invested by Philips in optical recording technologies as well as in the present and future research and development of new technologies. Currently, Philips is offering patent licenses for optical media in 5 mainstreams: CD, DVD, SACD, MPEG and AC3.

Texas Instruments instituted its current licensing strategy in 1985. Since then, the amount of revenues from royalties and licensing fees has increased steadily reaching $600 million in 1995, in some years more than what it earned from its normal operations. Over the last decade or so, Texas Instruments is estimated to have earned over $1.5 billion in licensing and royalty fees. Grindley and Teece (1997) point out that Texas Instruments' licensing strategy was enhanced by the stronger US treatment of intellectual property after 1982. Indeed, it benefited from what has been referred in the semiconductor industry as the "Texas Instruments" effect. Beginning around 1985-6, Texas Instruments successfully asserted its patents in court for a range of inventions pertaining to integrated circuits and manufacturing methods. This enabled the firm to earn higher royalty payments from other firms in the industry. Texas Instruments also has used strategically its large patent portfolio to establish R&D cooperation and joint ventures, and to bargain higher royalties in cross-licensing agreements with other players in the industry.

Monsanto. In 1997 Monsanto's chemical operations were spun off as an independent company, which initiated a comprehensive review of its technologies, scouting for potential candidates for licensing. Now, Monsanto is actively licensing its acrylonitrile technology and has recently begun soliciting licenses for its acrylic fiber know-how. The company is also looking opportunities to license processes that it has developed but that are not used in any of its businesses. At the same time, the company is evaluating opportunities for licensing-in technologies to bolster its R&D and process development efforts. As Bruce Greer, Monsanto's v.p. for growth and commercial development says "...There's no reason you have to reinvent the wheel..." (*Chemical Week*, 1997, July 23, p 45).

BOX 1: Selected web pages advertising the licensing of intellectual property

Company	WWW address	Available for licensing
Boeing	http://www.boeing.com/assocproducts/mdip/home.htm	Algorithms, laser technology and manufacturing, coatings, material processing, composite technologies, materials, factory hand tools, measurement system, fasteners, placement systems, video display, fiber optic sensors and demodulation systems
IBM	http://www.ibm.com/ibm/licensing	Processes used in integrated circuit, hard disk storage technology, device designs, source code
DuPont	http://www.dupont.com/corp/science/technologies.html	Fibers related, composites, chemical science and catalysis, analytical, environmental, electronics, biological
Union Carbide	http://www.unioncarbide.com/business/busprgde.html	Ethylene oxide/ethylene glycol, industrial performance chemicals, polyolefin resins and compounds, solvents, intermediates and monomers, coating materials, specialty polymers and products
Philips	http://www.licensing.philips.com	CD, DVD, SACD, MPEG, AC3
Procter & Gamble	http://www.pgtechnologytransfer.com	It is P&G own online market for technology
Several founding members	http://www.yet2.com	All types of technology. It is an online market for technology