MARKETS FOR TECHNOLOGY AND THEIR IMPLICATIONS FOR CORPORATE STRATEGY

by

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Abstract

Although market transactions for technologies, ideas, knowledge or information are limited by several well known imperfections, there is increasing evidence that they have become more common than in the past. In this paper we argue that these markets 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 "buy" technologies) and as technology suppliers (they can "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

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.

The growth and functioning of markets for technology might be limited by several factors, most notably the tacit and context specific nature of technological knowledge.[1] However, it is undeniable that when markets for technology exist they have major implications for firms' corporate strategies. The analysis of such implications is the main goal of this paper.

Markets for technology affect the role of companies both as technology users (they can "buy" technologies) and as technology suppliers (they can "sell" technologies). This changes 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. Thus, for example, entrepreneurial startups may be able to focus more narrowly on developing technology rather than on its application, by relying on licensing and other arrangements to appropriate the returns to their innovative efforts. Given that manufacturing and commercialization require substantial resources, which smaller firms may be unable to mobilize, markets for technology may be critical for the very existence of high-tech startups. 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, increase competition and compress product lifecycles: all changes that 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

[1] Elsewhere (see Arora, Fosfuri and Gambardella, 2000) we study the nature and functioning of markets for technology and the factors which limit or encourage their growth. In this paper, we focus on the implications 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 would fail one or the other criterion. Often they involve quite detailed contracts and may be embedded in technological alliances of some sort.

The way technology is traded is linked to the peculiar nature of technology as an economic asset, and as a potential object of exchange. Technology 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

corporate strategy.

development of the technology, or its realization "from scratch".[2] Panel 1 summarizes our definition of the market for technology in the form of a simple typology, along with canonical examples for each case.

Panel 1: A simple typology of markets for technology

	Existing Technology	**Future Technology or component for future**
Horizontal Market / Transactions with actual or potential rivals	Union Carbide licensing Unipol polyethylene technology to Huntsman Chemicals	Sun licensing Java to IBM; R&D joint ventures or other technological alliances between rivals
Vertical Market / Licensing to non rivals	Licensing of IP Core in Semiconductors	R&D joint ventures or other technological alliances; Affymax licensing combinatorial drug discovery technology to pharmaceutical companies

Our definition of the market for technology is close to the one proposed by the US Dept. of Justice in its *Antitrust Guidelines for the Licensing of Intellectual Property* (US Dept. of Justice, 1995). The US Dept. of Justice defines markets for technology as 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 in Panel 1 also encompasses what the Dept. of Justice calls "markets for innovation", which are seen as markets for "futures" technologies. These include arrangements in which the parties agree to conduct activities, jointly or independently, leading to future developments of

[2] 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.

technologies that will be exchanged (or jointly owned) among them. This is typically the market for contract R&D and the various types of 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).

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.[3]

In recent years we have seen a number of examples of "strategic alliances", ranging from R&D joint ventures and partnerships, spin-offs, corporate venture capital, licensing deals, and a variety of "outsourcing" deals, signaling the increasing importance of transactions for intangible technology. In Arora, Fosfuri and Gambardella (2000), 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. Tables 1a and 1b show the total number and value of such transactions, by industrial sector,

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

between 1985 and 1997.[4] The value of a transaction is calculated here as the sum of licensing and royalty payments, and equity investments and R&D funding provided in return for licensing rights.

These tables show that there have been over 15,000 transactions in technology with a total value of over $330 billion, implying an average of nearly 1,150 transactions worth $27 billion per year. To put these numbers in perspective, note that the total R&D spending in the US, Japan, Germany, UK, France, Italy and Canada was about $340 billion, and non-defense R&D spending was about $300 billion in 1995. Thus, the value of the total technology transactions is about 9% of total non-defense R&D spending in the developed countries.[5] Although markets for technology are still in their infancy in many cases, the value of the transactions is already substantial. Table 1 also shows that the transactions are concentrated in few sectors, notably chemicals, software, electrical and non-electrical machinery, and engineering and professional services. These sectors together account for the bulk of transactions (both source and recipient of technology), and as expected, are also a net source of technology for other sectors. Our data also show that the number of these transactions has been steadily increasing over time (with the exception of the last two years in our sample, possibly reflecting incomplete reporting of transactions for these years).

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.

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[4] The data are from a commercial database provided by the Securities Data Corporation, the leading commercial provider of such data The SDC data are constructed from SEC filings (10-Qs), financial journals, news wire services, proxies and quarterly reports. We read through each transaction to verify that technology transfer was involved. From the description of the agreement, we also coded the granter or recipient of the technology, or whether there was a two-way flow of technology, such as a technology cross-licensing agreement.

[5] There are a number of possible biases going in both directions. We exclude outright acquisitions. Further, the figures for equity purchase may include payments for non-technology assets. Excluding these would reduce the value to about $15 billion per year. On the other hand, our database probably does not include a large number of smaller value transactions, and we are probably undercounting transactions from 1985-87, as well as 1996 and

(See Arora and Gambardella, 1998; and Arora and Fosfuri, 2000.) Similarly, technology trade is becoming 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 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.

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.[6] These assets include technology, production expertise and facilities, strong brand-name reputation, human assets, supplier networks and established marketing channels. Porter (1985; and 1990) argues that a competitive advantage arises when the firm can find ways for creating more value than its competitors (see also Barney, 1991). The resource-based theory of the firm (Penrose, 1959; Grant, 1991) suggests that to be sustainable, a

1997. Based on other studies, using IRS data on licensing and royalty fees, we estimate the value of these flows to be of the order of $50 billion per year.

[6] 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,

competitive advantage must be underpinned by resources and capabilities for which well-functioning markets do not or cannot exist. So, the firm builds a sustainable competitive advantage by having access to assets that its competitors cannot access. Barney (1986) notes that ultimately, the possession of such assets that provide sustainable competitive advantage must be rooted in imperfections in the resources used to create such assets, and these imperfections ultimately arise from differences in the expectations that firms hold about the future value of the assets. Dierickx and Cool (1989) argue that not all the resources or assets required to sustain competitive advantage can be bought and sold. Instead, such assets must be developed in-house, often over a period of time. Much of the thinking on technology strategy has approached the problem by implicitly or explicitly assuming that technological assets cannot be directly bought and sold. In this sense, our paper builds on the resource based view of the firm by analyzing what happens when some assets that were not tradable become tradable.

What are the consequences of such a missing market for technology? The immediate consequence is that the innovator must exploit the technology in-house. That is, in order to extract the value from the technology, it (or rather its services) must be embodied in goods and services which are then sold. Such goods and services must have lower costs or command higher prices, to deliver returns that are greater than the competitive rate of returns – firms earn "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

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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.

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 technology. Similarly, firms that can exploit the technology on a bigger scale will be able to derive greater value (Cohen and Klepper, 1996; Klepper, 1996). If these complementary factors are themselves not traded on a competitive market, or if firms differ in their access to such capabilities, then firms that have superior access to these complementary capabilities, typically because they control them in-house, 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 technology, a firm must often incorporate other, complementary, assets in order to extract profits from the technology. 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. In this case, the relative importance of complementary assets that exist within the boundaries of the individual firms diminishes compared to the existence of such complementary assets at the level of industries or markets as a whole. Clearly, as we shall also note below, transaction costs or related factors may increase the cost of acquiring the complementary assets externally compared to owning them in-house, even when such markets exist. In a companion working paper we distinguish between cognitive factors (such as context dependence and absorptive capacity), contractual problems and other market imperfections that can limit the ability of firms to access external complementary assets (Arora, Fosfuri, and Gambardella, 2000). As these imperfections become less important, then, to use Teece's terminology, the existence of co-specialized assets at the level of markets or industries may offset the lack of such complementary assets at the level of the firm.

Ultimately, 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, or it may choose to buy it from external providers rather than develop it in-house. This does not mean that companies would only acquire technologies from external sources. Leading companies would probably choose the right balance between external acquisition and in-house development of technologies, even though for companies with lower in-house technological capabilities the existence of external technology sources may be critical to enhance their ability to produce and sell more innovative goods. Similarly, a market for technology assets does not mean that innovating firms will become pure licensing companies, although several small (and not so small) firms have been successful as specialized technology suppliers. Rather, as we shall also note 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. In turn, this implies that when there exists a well-functioning market for an asset, such an asset cannot be a source of sustainable competitive advantage and firms have to look somewhere else for gaining an edge over competitors (Barney, 1986; Dierickx and Cool, 1989).

3.2 Markets 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 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, even though he warns 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.) Since risk is sometimes worth the additional reward, the innovator now has the option to balance her ability to extract value from the asset by embodying it in products and services, against the transaction costs involved in trading the technology. In this respect, licensing is an option, not mutually exclusive with self-production. Hence, with a market for technology, a firm needs to recognize what its core, non-tradable and tradable competencies are. Having done so, it can 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 can be profitably licensed.

The decision on whether to exploit the technology 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. Otherwise, it is far more likely that the relevant complementary assets will be more broadly distributed, so that licensing the technology 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 costs 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 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. In the early 1990s, 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

The decision by a large established company of whether or not to license its technology is the result of two main forces pushing in opposite directions: the "revenue effect" and the "profit dissipation effect" (see Arora and Fosfuri, 2000). Licensing forces a trade off: 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 product market share (and by implication, possessing the required complementary capabilities) are better off exploiting the technology in-house. On the other hand, if the product 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, Procter & Gamble, DuPont, Boeing 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. Panel 2 reports information from the web sites of some leading corporations wherein they advertise internal technologies available for licenses. Some of these companies have even created special internal division that focus on the licensing of their technologies. The Appendix provides further evidence of this change in attitude by discussing short cases of some major corporations.

Panel 2: 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
Yet2.com (several founding	http://www.yet2.com	All types of technology. It is an online market for technology backed by several large US corporations (e.g. 3M, AlliedSignal, Boeing, Dow Chemical, Ford, Honeywell, Polaroid, Procter & Gamble, Rockwell)

members)		

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. These factor have 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.

Clearly, there are many reasons why firms license, and not all of them can be ascribed to the specifics of markets for technology that we are trying to advance here. For instance, 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 technology strategy to seek additional returns from their R&D efforts by selling their technologies disembodied from products.

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. Recent work by Grandstrand (1999) and Rivette and Kline (1999) details 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. Grindley and Teece (1997) also 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 a means for generating revenues in alternative to direct production. In turn, this implies that 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. (See ETAN, 1999.) 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 importance 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.[7]

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).

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

[7] 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.

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.[8] The choice depends not only on the efficiency of a market for technology, 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 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

[8] 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.

transfer, depends critically upon manufacturers of semiconductor devices, notably Intel, for its survival.[9] 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 startup may not be 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.[10] 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

[9] 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.

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 often may not be able to manage downstream activities efficiently. 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 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

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[10] 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,

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 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,

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such as Kmart.

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.[11]

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

Markets for technology also affect the 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 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.

[11] As against this, Kline and Rosernberg (1986) explain in their chain-link model of innovation that these assets may 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.

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”.[12]

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 improve the innovation

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[12] 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

potential and the competitiveness of companies in technologically and possibly economically less dynamic regions. These markets permit 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 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 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

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found specialist individuals or institutions that could potentially offer valuable technical consultancy services in the specific domain of their project.

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. INDUSTRY-LEVEL EFFECTS: VERTICAL SPECIALIZATION, ENTRY AND COMPETITION

At the industry level, markets for technology can potentially give rise to significant industry-wide economies of specialization in the production of technology, especially if they encourage the formation of specialized technology suppliers. Markets for technology may then provide the downstream industries with the classical Smithian and Stiglerian advantages of division of labor.

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 World War II 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. As with any division of labor, the advantages of vertical specialization then translated into greater efficiency in the downstream industry as well. (See also Freeman, 1968.) Over time, the advantages that specialized engineering firms enjoyed in design and construction of certain types of chemical plants made them the preferred source for such services. In many cases, these specialized firms also provided in-house proprietary technology, often on very attractive terms. This reinforces our earlier point that that when markets for technology exist, the penalties from not monitoring the opportunities that are created by them, or from not using these markets, or even worse, from insisting with the "not-invented-here" syndrome, can be substantial.

Markets for technology lower barriers to entry, especially when they give rise to an industry of specialized technology suppliers. For instance, while SEFs originated as an American phenomenon, during the 1950s and the 1960s US SEFs became a source of technology for the European and Japanese chemical industry. This enabled the European and Japanese chemical producers to rise and grow, and to compete with the US chemical companies in the international market. Similarly, SEFs from the advanced countries nowadays supply technologies to the chemical producers in the less developed countries, and these companies compete with the chemical industry of the First World in the developing country markets largely thanks to the availability of Western technologies. More generally, in the international context, markets for technology can lead to a dramatic shortening of the product life cycles.[13]

The example also highlights a closely related point. Markets for technology may reduce the importance of technology as a source of competitive advantages. The point is not that technological superiority in chemical processing is unimportant. 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) did not disappear. However, the presence of the SEFs meant that this gap was reduced, and the entry by newcomer chemical firms with no

[13] The pattern just described is not different in several high-tech industries today. Specialized suppliers in biotechnology, software or semiconductors accrue typical advantages of specialization in their areas of technological expertise. Moreover, while many of these specialized technology suppliers originated in the US, and they are still largely US-based, their services and technology are available to the European and Japanese companies as well, which have entered into a number of licensing agreements and other types of alliances with US technology-based firms.

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.[14]

One natural response to the increase in competition produced by markets for technology is that firms have to cut costs, possibly by exiting businesses in which they lack a clear source of advantage. To the extent that technology becomes a relatively less important source of competitive advantages, another response is that firms have to look for other distinctive competitive assets.[15] Indeed, as we have discussed in section 3.1, the resource-based theory of the firm argues that a competitive advantage is sustainable only if it is underpinned by resources and capabilities which are scarce and imperfectly mobile. 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 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

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

[15] 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.

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.[16]

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 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.

8. CONCLUSIONS

[16] 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 they operate commercially.

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 companies, and in panel 3 we summarize the main implications of the rise of markets for technology highlighted in the previous sections.

The most obvious implication is that leading companies 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 also involve firms as technology "buyers", the growth of such markets increases the importance of external monitoring of technological developments, and it increases the penalty of insularity and the "not-invented-here" syndrome. Markets for technology can also 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 an obvious candidate. Thus, markets for technology may actually increase the importance of downstream strategies for differentiation.

Finally, note that the rise of markets for technology is not inexorable but 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 19th and early 20th 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.

Panel 3a: Implications of markets for technology for technology suppliers

- ***Large technology-based firms***
  - ⇒ Increased strategic options -- firm can choose to license rather than only use the technology in-house;
  - ⇒ Will license if profit dissipation effect from licensing (increased competition) is smaller than revenue from licensing – for instance will license:
    - ➢ In "distant" markets (where it is costly to produce)
    - ➢ If own market share is small (e.g. "unused" technologies)
    - ➢ If downstream market is highly competitive (as profit dissipation from an additional competitor is smaller)
  - ⇒ Prompts effective internal management and organization of own intellectual property
- ***High-tech start-ups***
  - ⇒ Can focus on technology with related advantages of specialization;
  - ⇒ Need not incur costly and risky investments in downstream assets, and can be formed even if they lack such complementary assets or if the markets for such complementary assets are underdeveloped and costly
  - ⇒ Encourages formation of high tech start-ups by
    - ➢ Increasing strategic options for startups
    - ➢ Reducing cost and risk of failure

Panel 3b: Implications of markets for technology for technology Users

- ***Technologically advanced users***
  - ⇒ Increased penalty of the "not-invented-here" syndrome – e.g. because of
    - ➢ Costs of duplicative research efforts
    - ➢ Potentially cheaper technologies available from specialized supplier industry
    - ➢ Potential external availability of complementary technologies
  - ⇒ Encourage active external monitoring of available technologies

- ***Technologically laggard users***
  - ⇒ Can acquire technologies possibly at competitive prices, which would otherwise be unable to develop;
  - ⇒ Technology becomes a less important source of competitive disadvantage;
  - ⇒ Encourage active external monitoring of available technologies

Panel 3c: Implications of markets for technology corporate strategy

- ***Creates of division of labor and vertical specialization***
- ***Lower entry barriers and intensify competition, which induce companies to***:
  - ⇒ Re-organize and re-structure their business, and cut costs for efficiency
  - ⇒ Look for distinctive competitive assets other than technology through customization, higher service-content in products, investments in information about differentiated requirements of markets and users

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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.[17] 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. (See Box 1.)

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 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

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[17] "...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).

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).

Table 1 A: The Market for Technology: Number of Technology Transactions, 1985-97, by Sector

YEAR	1985-89	1990	1991	1992	1993	1994	1995	1996	1997	Total Number
28	439	310	461	395	486	596	351	208	222	3496
35	129	115	210	188	195	192	164	63	69	1360
36	234	190	310	316	366	415	326	135	151	2479
73	143	207	360	334	363	610	770	405	424	3689
87	11	9	45	253	156	73	34	22	17	707
All Others	174	209	468	523	560	540	545	289	293	3858
Total	1130	1040	1854	2009	2126	2426	2190	1122	1176	15073

Table 1 B: The Market for Technology: Value of Technology Transactions, 1985-97, by Sector (millions of 1995 dollars, all countries)

YEAR	1985-89	1990	1991	1992	1993	1994	1995	1996	1997	TOTAL VALUE
28	5809	4102	6101	5227	6431	7887	4645	2753	2938	46264
35	6280	5599	10224	9153	9493	9347	7984	3067	3359	66211
36	10971	8908	14534	14816	17160	19457	15284	6329	7080	116227
73	1740	2518	4380	4063	4416	7421	9368	4927	5158	44881
87	171	140	701	3939	2429	1137	529	343	265	11009
All Others	2781	2901	5471	6373	6549	6354	6658	3342	3156	48240
TOTAL	27753	24169	41410	43571	46479	51604	44469	20761	21956	332831

Note: SIC28 = Chemicals; SIC35 = Industrial Machinery & Equipment; SIC36 = Electronic & Other Electric Equipment; SIC38 = Instruments & Related Products, SIC49 = Electric, Gas, and Sanitary Services; SIC 50 = Wholesale Trade – Durable Goods; SIC73 = Business Services.

Source: Our computations based on SDC datafiles. See Arora, Fosfuri and Gambardella, 2000 for details.