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Innovation Inside and Outside the Company: How Markets for Technology Encourage Open Innovation

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1. INTRODUCTION

In recent years considerable attention has been devoted to the phenomenon of "open innovation" (Chesbrough, 2003). In a nutshell, the sources for innovation are no longer largely internal in a firm, but have spread to many *loci* in the outside environment. There are different sources of open innovation. A classical one is knowledge spillovers, which arise when firms can capture knowledge or information "in the air", as Marshall put it. Recently, there has been an upsurge in the so-called "open source" phenomenon whereby knowledge and information are distributed openly by their producers, in a context where the production and distribution of knowledge are governed by well-defined norms (e.g., Lerner and Tirole, 2002). An "old" form of open source is open science, which is again based on clear norms of production and diffusion of knowledge (Dasgupta and David, 1994). Open science, and particularly the proximity of firms to universities or other scientific institutions, have themselves been considered sources of knowledge spillovers (e.g., Alcacer and Chung, 2007).

While both spillovers and open source (or open science) are important sources of open innovation, this chapter focuses on the acquisition or distribution of knowledge that depends on a standard economic mechanism—that is, market-mediated forces. While spillovers or open source imply exchange of knowledge based on forces or norms other than markets, in this case knowledge is exchanged at a price. This price may take several forms—e.g., licensing royalties, profit sharing, co-development or supply of resources for innovation. But what distinguishes this source from the others is that knowledge is traded. As we shall see, this trade is more complicated than that of standard commodities, and has far more limitations. However, not only is it possible, but it has become more and more significant in recent years.

We shall discuss the notion of technology trade in a broad sense. While the classical example is licensing agreements, whereby one firm sells technology to another firm in exchange for money, we include more elaborate forms of technology transaction, in particular alliances or other collaborative arrangements for the development of innovation. We remain deliberately vague on this definition to let the reader interpret technology trade in the way he or she prefers.

The reason why we focus on these market-mediated forces is twofold. First, as noted, they have grown in recent years. For example, from 1980 to 2003 in the G8 countries, technology royalty payments and receipts increased annually by an average of 10.7% and reached an annual volume of approximately US$190 billion in 2003 (OECD, 2006). Arora *et al*. (2001), as well as Arora and Gambardella (2010a and 2010b), provide additional systematic evidence of these trends. Second, markets are in general an important institution for economic growth. I am sure that a good deal of knowledge is diffused today via spillovers, open source, or open science, and in this chapter I do not want to discuss or claim any superiority of the market mechanism with respect to these other forces. However, the formation of markets for knowledge, or markets for technology are crucial for many aspects of the growth of knowledge, its diffusion, or the ability of firms to use knowledge as a resource more effectively. Moreover, they create new strategic options for firms, as firms can decide whether to buy, make or sell technology. Without such markets the only strategic option for product innovators is to produce their own technology, and for the technology makers to invest in the downstream assets to sell the product that embodies the technology.

The goal of this chapter is to discuss the factors that make the rise of technology markets possible, along with the limits to their development. I then examine a number of implications for industry structure and company strategy. Specifically, the chapter is organized as follows. The next section provides a general overview of the nature and limits of technology markets. The following section discusses the implications of the absence of markets for assets, highlighting what we can expect to observe when such markets exist. We then deal with three main limitations to the formation of technology markets: a cognitive limitation, i.e., in trading knowledge it may be hard to identify the object of exchange; a transaction cost limitation, i.e., one needs proper institutions for these markets to function; a degree of market limitation—i.e., knowledge has special properties which imply that only under certain conditions does a given piece of knowledge have a market large enough to justify its trade. We conclude by discussing some implications for industry structure and company strategy.

This chapter draws on my research on this topic with Ashish Arora and Andrea Fosfuri. Here I summarize some of the main issues and implications of our work. While they are of course not responsible for any drawbacks or limitations in this chapter, I encourage the interested reader to look at Arora *et al*. (2001a), or Arora and Gambardella (2010a and 2010b), where we discuss at greater length some of the issues dealt with in these pages.

2. BACKGROUND

The exchange of technology between independent parties is not a novel phenomenon. In a series of articles, Lamoreaux and Sokoloff (e.g., 1996 and 1999) discuss the existence of an active market for patents in the US in the 19th century. Typically, inventors used to develop their own technologies which were then sold to firms that developed them and manufactured and commercialized the products, or employed them as process innovation. Interestingly, Lamoreaux and Sokoloff also document the existence of services and institutions

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in support of the technology trade, as we typically observe when markets exist. Thus, for example, patent lawyers supported both inventors and companies in their trade, special magazines or trade press provided information about the technologies to be sold, and the patent office itself was a crucial institution in this trade as it provided the certification of the property rights and of the novelty of the invention.

As Lamoreaux and Sokoloff themselves noted, the US market for patents shrank in the 1920s. One important reason is that the development of technologies became too risky and complex to be governed by individual inventors. For example, it required expensive equipment that the individual inventors, or their small firms, could not afford. A related reason was that knowledge itself became more complex and interdisciplinary, requiring the contributions of specialists in many fields. As a result, inventors were gradually employed by larger firms, which at the same time started to become large enough to bear the growing costs and risks of innovation.

To be sure, even in the mid-20th century many large corporations relied on outside sources of ideas, especially at the upstream end of the knowledge spectrum. For example, Mueller (1962) documents that quite a few of Du Pont’s major inventions in the first half of the 20th century came from ideas that it had acquired from external inventors or smaller firms. Arrow (1983) theorizes on this point. He notes that large and small firms have comparative advantages in different types of innovations or at different stages of the innovation activity. In large firms there is a greater organizational distance between the inventor and the manager who is responsible for financing the innovation. This implies that firms finance only projects in which the asymmetric information between the managers and the inventors is not excessive. But limited asymmetric information is typical of projects for which there is substantial knowledge and information, i.e., that are less risky and innovative. When projects are particularly innovative it is most likely that the inventor has more information than the manager, and in general the manager (or the external financier) takes a greater risk in financing them. Smaller firms, or even firms founded by the inventor, have a shorter organizational distance, which makes the problem of asymmetric information less severe. At the same time, larger firms have more internal resources to finance larger-scale projects and inventions. This is typical of the downstream development of initial innovations or ideas, or of more basic research projects that demand significant investment in large scale equipment or resources. As a result, small firms specialize in the development of riskier projects that demand fewer resources, while larger firms specialize in larger-scale projects, whether upstream or downstream. Given the complementarities between these two types of projects Arrow concludes that a "market for firms", whereby larger firms buy the smaller concerns that produce new ideas, can make our economies more efficient by giving rise to a division of labor in innovation based on comparative advantages.

Teece (1988) analyzes the reasons why a market for Research & Development (R&D) services encounters serious limitations. He argues that the interdependencies among tasks in the innovation process, and the natural uncertainty associated with development and commercialization of innovations, create at least three sources of transaction costs. First, it is hard to provide detailed specifications of the task requirements at the outset of the innovation process. These specifications can be defined more precisely while undertaking processes needing contracts that are largely incomplete and which potentially leave either party open to opportunistic behavior by the other. Second, if a company develops close interactions with one technology supplier, the interplay of relationships may generate sunk costs, which can give rise to switching costs and "lock-in" problems. Finally, releasing pre-contract information to bidders may require the companies to share valuable proprietary information, and increases the risk that competitors will discover its R&D plans.

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Teece (1988) concludes that these reasons explain why the creation, development, and commercialization of new products and processes have traditionally been integrated within firms. This is consistent with the classical view of Grossman and Hart (1986) and Hart and Moore (1990) who argue that vertical integration, and the authority it confers, help to solve the problems of opportunistic behavior that arise when contracts are incomplete. In the case of innovation, this means that a firm can specify and organize the actions of the various agents involved in the innovation process while the process is taking place. In a similar vein, Arrow (1975) develops a model showing that one of the determinants of vertical integration is asymmetric information about the quality of the supply. In addition, being part of the same organization helps the various specialists to acquire a better understanding of each other's problems and needs, to share common objectives and beliefs, and to adopt a common language (Arrow, 1974). This facilitates collaboration and information exchange, and increases the productivity of the innovation process.

Teece (1988) also points out that the problem is more severe in the case of more complex technologies, such as systemic technologies that require profound interdependencies between many activities, as compared to "stand-alone" innovations. He therefore acknowledges that the advantages of integrating the innovation tasks within the same organization can differ across industries and technologies. However, he also provides numerous examples showing how the lack of proper integration of R&D with manufacturing and commercialization leads to poor innovation performance. In short, the Teece (1988) perspective provides the natural theoretical support for the discussion found for instance in Chandler (1990) who argues that historically the advantages of larger integrated firms has been their ability to make systematic "three-pronged" investments in R&D, production and marketing.

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3. THE EFFECTS OF HIGH TRANSACTION COSTS IN THE MARKETS FOR CORPORATE ASSETS

In order to better understand the implications of markets for technology, it is useful to begin with a more general discussion of the implications of high transaction costs in the markets for corporate assets. Broadly speaking, these assets include technology, production expertise and facilities, a strong brand-name reputation, human assets, supplier networks and established marketing channels.

The resource-based theory of the firm suggests that to be a source of sustained above-average performance, resources must meet three criteria: they must be valuable, rare and imperfectly mobile (Barney, 1991; Peteraf, 1993; Markides and Williamson, 1996). In other words, a competitive advantage must be underpinned by resources for which well-functioning markets do not or cannot exist, or they will have high transaction costs. So, the firm builds a sustainable competitive advantage by having access to assets that its competitors cannot access. Barney (1986) notes that the possession of such assets must be rooted in imperfections in the factor market, i.e., the market where the factors used to create such assets are traded, and these imperfections ultimately arise from differences in the expectations that firms hold about the future value of the assets (Barney, 1991). Dierickx and Cool (1989) argue that not all the assets required to sustain competitive advantage can be bought and sold. Instead, such assets must be accumulated internally through a number of mechanisms over a period of time. Similarly, 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 and the services of such assets cannot be "rented". In the context of our analysis in this chapter, it is interesting to ask what happens when some assets that were not tradable become tradable.

The immediate consequence of an absent or highly imperfect market for technology is that the innovator has to mainly find the sources of 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 that are then sold. Such goods and services must have lower costs or command higher prices in order to deliver returns that are greater than the competitive rate of returns: so that firms can earn "quasi-rents".

Consider a case where a firm has developed a new cost-reducing technology for the production of certain goods. In order to extract value from the technology, the firm must use it to produce the goods. Not only does this require the firm to have access to the complementary assets (such as land and physical equipment, marketing channels and so on), but the returns also depend on the volume of output that the firm can produce and sell. If the complementary assets 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 assets will be able to derive greater value from the technology. Similarly, firms that can exploit the technology on a larger scale will be able to derive greater value from it (Cohen and Klepper, 1996; Klepper, 1996).

Continuing with this logic, larger firms or firms with superior access to complementary assets 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 assets that cannot be easily and efficiently acquired on the market. In other words, as Teece (1986) puts it, firms have to invest in creating co-specialized assets to maximize their returns from developing new technology. In short, in the absence of a market for technology, a firm must often acquire other assets in order to extract profits from the technology. Insofar as these other assets are themselves expensive and illiquid, well capitalized, large, integrated firms that possess such assets have greater incentives to invest in developing new technologies (Nelson, 1959). Conversely, smaller firms face major hurdles in developing and commercializing technology.

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The situation is quite different when the asset can be sold or rented. Complementary assets need not be owned or even directly accessed by the technology developer. The relative importance of complementary assets within the boundaries of the individual firms diminishes relative to the existence of such complementary assets at the level of industries or markets as a whole. Clearly, transaction costs or factors may increase the cost of acquiring the complementary assets externally relative to owning them in-house, even when such markets exist. However, as these imperfections become less important, then, to use Teece's terminology,

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the existence of complementary assets at the level of markets or industries may offset the lack of such assets at the level of the firm.

Ultimately, a market for the asset provides the innovator—a firm that has developed the 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 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 might 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, the appropriate strategy in the presence of technology markets 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. As we shall discuss in section 5 below, a technology market lowers entry barriers and increases competition in the product market, which often implies a rethink of existing strategies. In turn, this implies that when a well-functioning market for an asset exists, such an asset cannot be a source of sustainable competitive advantage and firms have to look somewhere else for gaining an edge over competitors. This is an important consequence of technology markets. When they exist, technology cannot be retained in exclusive ways. By contrast, one area that retains its exclusive nature is likely to be the knowledge of customers and markets, and the assets that link these markets and clients to a specific firm vs. its competitors. This knowledge, and the underlying assets depend on sizable investments and a good deal of experience with such markets and clients. To the extent that the markets for these assets remain less perfect than the technology markets, commercialization capabilities, market information, and other downstream assets, may become better sources of differential advantages vis-à-vis the competitors.

4. LIMITS AND OPPORTUNITIES IN THE GROWTH OF TECHNOLOGY MARKETS

4.1. Uncertainty and cognitive limitations

An important limit in the growth of technology markets is that the key objective of exchange, knowledge or technology, is characterized by significant uncertainties. This is especially true when technology is not codified, is embedded in people or machines, and is largely based on experience rather than general principles. For example, improvements in a production process or in a service may be hard to define and codify with precision. In these cases, the object of the transaction is ill-defined to begin with, and this ambiguity makes it harder to trade in the improved process.

Arora and Gambardella (1994) argue that the increase in the extent to which industrial technologies are based in science (including engineering sciences), and the use of advanced instruments and computers, are reducing the fraction of "inarticulable" technology. Thanks to advances in computer technology, including software, many technical problems (e.g., in design, semiconductors, biotechnology, and many other industries) can be defined in logical terms (e.g., mathematical language) and captured in software. Interestingly, there are useful synergies with patents in facilitating technology transactions. Codified technology is easier to patent. Conversely, an increasing appreciation of intellectual property rights encourages codification of innovations.

The difficulties, however, are not only contractual. Discovering who has relevant technology and the price at which they may make it available (if at all) is also difficult. Understanding what they have and how to use it amplifies the problem. Conversely for a seller, identifying potential buyers can be problematic, and once a prospective partner has been identified, settling on the price can be no less challenging. Moreover, new technologies are often surrounded by commercial uncertainty (Rosenberg, 1996). Simply put, it is difficult to know what applications the technology can have. This raises the search costs of both buyers and suppliers and leads to considerations of option values rather than actual values, and renders potential transactions subject to a variety of biases to which human beings are prone when faced with uncertainty. The net result is that technology transactions are more imperfect and harder to accomplish.

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4.2. Patents as a solution to the contractual limitations in technology trade?

Teece's (1988) limitation discussed earlier is fundamentally a limitation in our ability to write contracts involving an ill-defined object like knowledge or technology. Arrow's (1962) solution to the classical problem of information exchange is to appeal for intellectual property protection. If protected, the seller could disclose the details to potential buyers, mitigating the problem. This close relationship between patenting, the technology market, and specialization in invention is reflected in trends in patenting and measures of the technology market. Lamoreaux and Sokoloff note that patenting per capita in America rose during the 19th century, peaked in the early 20th century, and then declined thereafter, closely mirroring

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trends in individual inventor activities and in trade in patents. After the mid 1980s, patenting per unit of R&D investment in the US changed course and began to rise, very close in time to the resurgence in technology markets as well (see Arora and Gambardella, 2010a).

From a theoretical point of view, Arora (1995) provides a model that clarifies some important conditions under which technology trading can occur, and the role of patents in this process. Many trades in technology actually come with the provision of complementary services—like the provision of know-how and technical services—along with a blueprint technology, like a licensed patent (Taylor and Silberston, 1973, Contractor, 1981). Arora models the case where, along with the technology, the licensor also has to transfer know-how. Given the difficulty in objectively verifying that the know-how is provided, the licensor has an incentive to skimp, since providing such know-how services is costly. Conversely, insofar as some payments are conditional on the provision of the know-how, the licensee has an incentive to withhold payment, claiming that inadequate know-how was provided.

The model shows that these problems can be solved by staggering the payment to the licensor over time and by relying on the property rights of the technology. The buyer’s value depends on the technology and the know-how. While the know-how that is transferred cannot be withdrawn, by withdrawing the rights to use the technology, the licensor does have a hostage because the know-how without a license to the patent is of diminished value. In some cases, the bundling with other complementary inputs, such as specialized machinery can provide a similar role (e.g., Arora, 1996).

The empirical literature provides mixed evidence on the relationship between patent protection and technology licensing contracts. Using a sample of 118 MIT inventions, Gans, Hsu and Stern (2002) find that the presence of patents increases the likelihood that an inventor will license to an incumbent rather than enter the product market by commercializing the invention (see also, Decheneaux *et al*., 2008). Anand and Khanna (2000) find that in the chemicals sector, where patents are believed to be more effective, there are more technology deals, a larger fraction of these are arm’s length, involving exclusive licenses, and a larger fraction of licensing is for future technologies rather than existing ones. In contrast, Cassiman and Veugelers (2002) do not find that more effective patents encourage Belgian firms to enter into collaborative R&D arrangements. Evidence from cross-national data is similarly mixed (see Arora and Gambardella, 2010a)

Arora and Ceccagnoli (2006) provide a potential resolution of this mixed evidence. They argue that when licensing is attractive, then patent protection facilitates licensing. However, for firms with the ability to commercialize technology themselves, patent protection also increases the payoffs to commercialization. Analyzing data from a comprehensive survey of R&D-performing firms in the U.S., they find that patent protection increases licensing, but only for firms that lack complementary manufacturing capabilities. Hall and Ziedonis (2001) provide similar evidence from the semiconductor industry: all else being equal, small design specialists are more likely to patent, and case- study evidence suggests that they do so to license their technologies.

4.3. General-purpose technologies and the size of technology markets

Much of the discussion thus far has focused on the factors that affect the cost and efficiency of technology transactions. Hence Adam Smith's well known observation that "the division of labor is limited by the extent of the market". Thus, even if one could successfully solve the contractual problems, a fully-fledged division of labor in the production and utilization of knowledge and technologies would depend on the size of the market for their applications.

To understand this issue one has to better define what is meant by size of the market in the case of technology. Suppose that a certain body of knowledge or a certain technology is specific to a given application by a particular firm. The context-specific nature of the knowledge and technology would then imply that it is difficult to "re-use" it for other applications. In these cases, the R&D cost can only be spread over the volume of production of the goods associated with the given application. But this implies that the potential supplier would not have any economic advantage in the R&D activity relative to the firm that produces and sells the goods, because the market size of the technology would not be much larger than that of the goods to which it is applied. Moreover, the comparative advantages of the supplier would not increase, if the size of the market (for those goods, and hence for that application) were to increase. In other words, if a specialized supplier is restricted to a single buyer, there is no advantage to specialization that can offset the inevitable costs of transaction and others involved.

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various applications or users, at least parts of the technology and knowledge bases can be re-used at zero or very low incremental costs. Under these conditions, specialized suppliers would have an advantage over any individual user because although the user could also re-use the knowledge, he or she would do so much less frequently than would a specialized supplier serving a number of users.

In short, what we suggest here is that technology markets and specialized technology suppliers are more likely to arise in the case of general-purpose technologies (Bresnahan and Trajtenberg, 1995; Rosenberg, 1976), or when the technology relies on “general and abstract knowledge bases” (Arora and Gambardella, 1994). General-purpose technologies, or GPTs, are technologies that encompass several applications. Since the fixed cost of developing a GPT can be spread over many potential applications, the efficiency of specialized GPT suppliers increases as the number of applications to which the GPT is applied increases. Thus, specialization advantages arise with increases in the size of the market, insofar as the increase is due to an increase in the number of potential users of the GPT rather than an increase in the size of the individual user or application.

Bresnahan and Gambardella (1998) develop a model in which they argue that the size of the market has two components: N, which is the number of diverse applications of a given technology, and S, the average size of each application. They show that as N increases, a vertical division of labor becomes more likely: technology-specialist firms produce GPTs supplied to the downstream producers that operate in different segments of the final market. As S increases, downstream firms are more likely to integrate backward to produce dedicated technologies for their business. Dedicated technologies are customized and co-specialized for a given application, but they cannot be used for other applications. GPTs can be employed for many applications, but they are less effective than a dedicated technology in any of them.

The intuition is that with high N, a specialized technology supplier can gain economies of scale at the level of the industry. To do so, however, the supplier has to produce a general technology to be offered to the different downstream segments of the final market. By contrast, with high S the final market of a specific application is large enough to justify a fixed cost investment in a technology dedicated to it. Thus, a large N encourages the production of GPTs, and through them the exploitation of economies of scale at the industry level associated with the breadth of the final market. A large S encourages instead the production of dedicated technologies and the exploitation of economies of scale at the level of the firm (or application) associated with the depth of the final market.

Bresnahan and Gambardella discuss the example of the Japanese machine tool sector that developed compact general-purpose machines for the differentiated needs of small final producers in many manufacturing industries. By contrast, in the US, machine tools were technologies largely dedicated to the need of the large automobile industry. The argument is not country-specific, because as they also point out, the roles are reversed in the case of software. In the 1980s, the large PC market in the US, which catered to many different types of users, led to the production of general-purpose packaged software created by specialist vendors. In Japan there were fewer PCs, and computers were largely mainframes owned by large users for specialized applications. As a result, Japan had many large providers of custom software but few independent software package producers. Moreover, users often developed their own software.

Arora *et al*. (2009) test the predictions in Bresnahan and Gambardella using data from the chemical plant engineering sector. In their model, large chemical firms (those investing in more than one plant) choose whether to design the plant internally or engage an external supplier of design and engineering services—the specialized engineering firms, or SEF. Small firms either use an SEF or do not enter the market. They generalize the model by allowing the number of SEFs operating in a market to depend on the demand for their services, and therefore on the decisions of potential buyers, i.e., the chemical firms. Consistent with the theoretical predictions in Bresnahan and Gambardella (1998), they find that the number of SEFs increases when the market expands through an increase in the number of potential buyers but not when market expansion is due to an increase in the average size of buyers.

Today, there are growing examples of GPTs and a rise in related technology markets. Gambardella and McGahan (2010) discuss several of them, and the business models of the technology specialists. For example, Maine and Garsney (2006) discuss the stories of two nanotechnology companies—Hyperion Catalysis and Cambridge Display Technology (CDT). Hyperion Catalysis has developed special applications of fullerenes, carbon allotropes discovered in 1985 that represent a general technology with many potential applications based on basic nanotechnology materials research. Initially Hyperion struggled to find applications for its new materials, and ultimately explored applications via alliances with manufacturers, automotive, aerospace and power generation companies. This has proved a successful strategy, as Hyperion has commercialized more than 40 products in these four distinct markets. CDT has developed polymers that emit light, another general technology with potential applications in semiconductors, consumer electronics and toys. Again, licensing and alliances with several manufacturers have provided the company with paths towards downstream markets.

5. IMPLICATIONS OF MARKET-MEDIATED OPEN INNOVATION PROCESSES

5.1. Efficiency gains from a division of labor in innovation, and a higher rate of innovation

There are many implications of market-mediated open innovation processes. In this concluding section, we discuss three of them: at the level of economies as a whole (this subsection); at the level of industries (the next subsection); and at the level of the individual firms and their strategies.

A technology market creates advantages related to the possibility of creating specialization and division of labor based on

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comparative advantages. The argument is the one suggested by Arrow (1983), which we discussed earlier. Different types of firms or agents can specialize in the activities where they are relatively more efficient—e.g., smaller firms in upstream riskier, innovative, projects, and larger firms in downstream or large-scale research projects. The exchange between them creates gains from trade that enhance the overall efficiency of the innovation process.

The gains from trade in technology have three sources. First and foremost, there are advantages related to cost savings for not reinventing the wheel. This aspect is particularly salient in international technology licensing (a country does not have to reinvent what has been invented in another country), and in the discussion of GPTs (an industry may not have to reinvent what has been invented in another industry and can be reused in it). The second source of gains from trade is comparative advantage. Sometimes the inventor of a technology is not the best equipped to develop or market it. Engaging in marketing may even retard innovation, by diverting attention and changing the nature of the organization. Licensing to another firm with a comparative advantage in manufacturing and marketing will yield gains to both parties. The third source of gains is more obvious. For instance, a firm may develop a technology that it does not wish to use but which is applicable elsewhere, and it can gainfully license (or sell) it.

Finally, a division of labor encourages more firms to invest in innovation. To the extent that revenue from innovation is earned only if firms also invest in costly downstream assets, smaller firms, without such capabilities, will on many occasions give up. This is also related to the risks of the innovation process. Low- cost exploration for innovations may entail a small loss in case of failure. The loss will be far more serious if the firm has to invest in marketing capabilities as well. By contrast, firms can try out many innovations if they know that they can sell their intermediate technological outcomes to established firms that already own these assets. In high-tech industries like software, semiconductors, or biotechnology, it is common for new or smaller firms to be set up to explore one innovation. If the innovation fails, the firms can exit the market at small cost, or sell their competencies.

5.2. Implications for entry, competition and industry structure

By definition, open innovation makes technology available more broadly to a larger set of firms. A technology market is an effective mechanism for this process. This reduces entry barriers, increasing competition in product markets. In a world in which the firms have to produce the technology that they use, any ability

> “Technology markets are then the mechanisms that link the growth of first-world markets to the growth of developing-country markets, where the latter is prompted by the higher investment in plants induced by the larger number of SEFs”

or specialization downstream can be undermined by a firm’s weakness in developing the technology. By contrast, with technology markets, these firms can use technologies that are developed more efficiently by others, and thus focus on their comparative advantages in the product markets. This raises competition because these firms will be more efficient competitors if they don’t have to develop the technology in-house. In some cases, this encourages the entry of firms that would not be able to enter the product markets if they had to develop the technology internally.

The impact of licensing on entry is evident in the chemical industry, which has a long history of licensing of chemical processes (Arora and Gambardella, 1998). Lieberman (1989) finds that licensing was less common in concentrated chemical products, and that when licensing was restricted, there was less entry. In a related study of twenty-four chemical-product markets, Lieberman (1987) reports that patenting by outsiders was associated with a faster decline of product price, once again suggesting that patenting by outsiders encouraged entry into the product market.

Arora *et al*. (2001b) provide more direct evidence in their study of investments in chemical plants in the developing countries during the 1980s. They find that a higher number of SEFs that provide engineering services in product markets is associated with a larger volume of investments in chemical plants by developing-country firms. However, the number of SEFs does not affect investments in developing countries by large multinationals. These multinationals are well-established firms with strong technological capabilities, and thus it is not surprising that they are not affected by the presence of SEFs. By contrast, the domestic chemical firms in the developing countries are technically less advanced but may have an advantage in producing locally. This illustrates the point that technology suppliers—the SEFs in this case—differentially benefit technically less-advanced firms.

This suggests that the division of labor created by the technology markets can be seen as a pecuniary form of externality or spillovers. Spillovers are widely regarded as important in the process of industrial development and economic growth. Yet, much of the research on spillovers focuses on non-pecuniary spillovers, or even more narrowly, on the involuntary (and uncompensated) transfer of knowledge. The SEF story suggests that a market-mediated division of innovative labor can be an important mechanism of knowledge transfer as well. Thus, for example, the growth of the product markets in the developed countries induces the rise of SEFs, which serve the chemical firms in the developing countries. Technology markets are then the mechanisms that link the growth of first-world markets to the growth of developing-country markets, where the latter is prompted by the higher investment in plants induced by the larger number of SEF**s**.

Importantly, these spillovers can also occur across sectors, as our discussion of GPTs suggests. In his study of the US machine tool sector in the 19th century, Rosenberg (1976) noted that the various downstream industries using machine tools started up at different times. For instance, firearm manufacturing emerged earlier than sewing machines, typewriters or bicycles. The growth of the firearm industry spurred the development of metal-cutting and shaping machines. Bicycle production required metal-cutting operations that were very similar to those of the firearm industry (e.g. boring, drilling, milling, planing, grinding, polishing, etc.—see Rosenberg, 1976), and thus the bicycle industry could rely upon the suppliers of metal-cutting machines that were already serving the larger firearm industry. What the suppliers had learned in producing metal-cutting machines for the firearm producers did not have to be learned again to supply bicycles producers. The commonality in the learning process across the industries, or what Rosenberg called "technological convergence", was critical for the transmission of growth, but required the intermediation of an upstream sector.

> "The commonality in the learning process across the industries, or what Rosenberg called "technological convergence", was critical for the transmission of growth, but required the intermediation of an upstream sector"

More generally, an important implication of MFT is that they shift the value of an industry chain downstream. As Dierickx and Cool (1989) suggest, the formation of a market for an asset means that the asset—technology in our case—is no longer strategic to the firm in the sense that it can be used to outcompete others. Markets do not currently exist for assets such as knowledge of markets and customers and for some types of production and distribution assets, and firms can leverage them to obtain a competitive advantage over their rivals. For example, Arora and Gambardella (2005) argue that while innovation in software has grown considerably in emerging economies like India, software innovation in advanced economies continues to derive an important advantage from proximity to lead users. Software innovation depends crucially on close interaction with lead users. These users—e.g., advanced telecom, computer, manufacturing or service firms—are still more unequally distributed worldwide than the capability of producing software innovations.

5.3. *Implications for company strategy*

Technology markets increase the strategic options of firms. Without them, firms can only make their technologies and use them internally. Now they can buy or make technology, and on the supply side they can profit from their technologies either by using them or by selling them, or both. In Arora and Gambardella (2010a) we discuss at some length how technology markets affect the strategic behavior of companies as technology buyers. Here we focus on their strategic options as technology suppliers.

Arora and Fosfuri (2003) develop a framework to understand the decision of firms to sell technology, and how product-market and technology-market competition condition this decision. In their model, multiple technology holders compete, both in the technology market and in the product market. Technologies are not perfect substitutes for each other, and neither are the goods produced from the technology. In deciding whether to license or not, the technology holder has to balance the revenue from licensing and the rent-dissipation effect produced because licensing will increase product market competition. As a result, factors that enhance licensing revenue or that reduce rent-dissipation will encourage licensing.

This tradeoff depends upon competition in the product market. If the licensee operates in a "distant" market, rent-dissipation is small compared to when the licensee is "nearby". For example, the licensee may operate in a geographical market in which the licensor finds it costly to operate, e.g., because the licensor does not have the complementary downstream assets. Similarly, the technology could be used for a different type of product that the licensor may not produce. Arora and Fosfuri note that product market competition enhances licensing because rent dissipation falls faster than licensing rents as product market competition increases. Indeed, as is well known, a monopolist will not license. Consistent with this, Lieberman (1989) finds that licensing was less common in concentrated chemical products, and the limited licensing that did take place was by outsiders (non producers and foreign firms).

"Product market competition enhances licensing because rent dissipation falls faster than licensing rents as product market competition increases. Indeed, as is well known, a monopolist will not license"

Arora and Fosfuri also point out that licensing is more likely when products are homogeneous rather than differentiated. If products are differentiated, a licensee is closer in the product space to the licensor than to other producers, so that the rent dissipation felt by the licensor is greater than if the product is homogenous. Put differently, by licensing, a technology holder imposes a greater negative (pecuniary) externality on other producers when the product is homogenous. Consistent with this, Fosfuri (2006) finds that licensing is lower in markets where technology-specific product differentiation is high.

The Arora-Fosfuri framework also implies that smaller firms are more likely to license, because they suffer less from the rent-dissipation from additional competitors. The logic is apparent in the extreme case in which the licensor has no stakes in the downstream markets, and thus has no product market rents to worry about. This is also consistent with the observation that in many high-tech industries (e.g., biotechnology, semiconductors, software) suppliers often do not produce in the product markets for which they supply technology, and with the evidence provided by other studies in the literature, as discussed in Arora and Gambardella (2010a).

Gambardella and Giarratana (2010) generalize the Arora and Fosfuri framework by emphasizing the interplay between the generality of the technology and the fragmentation of the product markets. The generality of the technology makes it attractive to "distant" user firms, which implies that rents from licensing can be earned from firms in product markets different from that of the technology holder. Because the markets are distant in product space, the rent-dissipation is small, which raises the incentives to license.

Gambardella and Giarratana (2010) jointly consider both the licensing decision and the decision on the range of product markets that the technology holder will enter. The key assumption is that technology can be deployed in more product markets than is profitable for the technology holder to serve directly, suggesting that technology can have broader economies of scope than marketing and manufacturing assets, which creates opportunities for licensing. In particular, GPTs can be so broadly applicable that few firms are likely to exploit all the applications.

6. CONCLUSIONS

There are several conduits to open innovation: knowledge spillovers, open science, and more recently open source technologies. This chapter focused on a market-mediated mechanism. It shows that a good deal of the open innovation process can take place through this standard economic channel.

The role of technology markets is best appreciated by looking at what happens when they exhibit high transaction costs. The most significant implication is that any user of technology has to possess the resources and capabilities to produce it, and any producer of technology has to have the resources and capabilities to embody it in final products to be commercialized. This has natural constraints in that it foregoes the advantages of specialization and division of labor according to comparative advantages, with implied market-level inefficiencies. In addition, the rate of innovation is reduced because any inventor or technology-specialist firm can invest in innovation only if they also make the far more costly investments in the assets or the capabilities that enable them to enjoy revenue from the commercialization of the final products.

When technology markets function well, and make innovation open, entry and competition increase because technology is no longer the highly-guarded secret of some master firm or R&D lab. An important implication is that technology becomes less strategic as a source of competitive advantage of firms. Firms have to focus on other strategic assets, which are less open and more unique to each of them. Among others, one of such assets is the ability of the firm to secure customers and final markets through investments in downstream assets. This also suggests why many technology specialist firms make little or no revenue (e.g., the biotech firms—see Pisano, 2006) and a good deal of the revenue in the vertical structure of an industry accrues downstream.

From a strategic point of view, technology markets give firms more options. Apart from buying rather than making technology, they can sell their own technologies. This is a strategic choice that hinges on the comparison of the rents from licensing and the dissipation of rents caused by the nurturing of a potential competitor. As technologies become broader, and they have a larger span of applications than the ability of a firm to exploit all of them, this can become an increasingly feasible strategy.

This chapter neglects several important issues. For example, the demand for technology or uncertainty plays an important role in these markets and in the ensuing openness of the innovation process. Some of them are discussed in Arora *et al*. (2001a) and more recently in Arora and Gambardella (2010a and 2010b). The interested reader is welcome to consult these sources, and the many references therein, for further insights.

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