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Intellectual property in a knowledge-based economy: Patents to include vs. patents to exclude

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Abstract

The traditional perception of patents puts the emphasis on their importance to exclude imitators and to restore incentives to invent. This view is far too restrictive and at variance with many empirical and theoretical works. We show that these contradictions can be overcome by shifting from a traditional economic framework to a knowledge-based one. Such a move allows a renewed economic perception of patents, making them into essential instruments which serve not only to exclude potential infringers but also to "include" all the different stakeholders in the innovation process. Within this new approach the main role of the patent system is therefore to ensure the coordination among heterogeneous actors and to structure innovation activities. We illustrate our view by presenting the four polar cases of pharmaceuticals, electronics, software and biotechnologies.

Keywords: Intellectual property rights, incentives, coordination, R&D collaboration, collective invention
JEL Classification: L00

1. Introduction

The purpose of this work is to revisit the economic role of patents in modern economies. The traditional arrovian view – which considers patents as being instruments to exclude imitators and to increase incentives[1], stands in sharp contradiction with almost all the empirical works that have been done the past three decades (Scherer *and al.*, 1959; Taylor and Silberston, 1973; Mansfield, Schwartz and Wagner, 1981; Levin, Klevorick, Nelson and Winter, 1987; Cohen, Nelson and Walsh, 2000; Sakakibara and Branstetter, 2001; Arundel, 2001). These empirical studies suggest unanimously that firms do not consider patents as efficient devices to exclude infringers and to protect inventions[2]. Yet, more and more patents are issued each

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[1] Since the seminal contribution of Arrow (1962) laying the basis of the economic perception of patent, the latter is traditionally perceived as an instrument intended to raise individual incentives to innovate while preserving a minimal diffusion of knowledge towards society at large. According to this view, innovation faces a problem of appropriation, which decreases firm's incentive to invest in R&D. The patent system is expected to restore appropriation and therefore to increase incentives to do research (Patents provide incentives to invest in R&D but also to disclose knowledge, Andersen, 2003). The optimal design of patents results from a tentative balance between restoring incentives to innovation, knowledge dissemination, and static inefficiency.

[2] In most sectors patents are not essential to the implementation of the major part of firms' innovations (with one specific exception, namely the entire chemical based industries: pharmaceuticals, petroleum, etc.). Most studies

year. Worldwide patent statistics show that firms increasingly apply for patents. This upsurge is not accompanied by a significant augmentation of R&D budgets, which means that there is really an increase of propensity to patents and not simply an increase in research activities. It is therefore paradoxical to see that the more firms critic the efficiency of patent as a tool of exclusion, the more they apply for patents (Kortum and Lerner, 1999).

We believe that an explanation to this paradox can only be found by defocusing from the traditional economic framework and by embracing the wider framework offered by knowledge-based economics. In such a renewed framework, a double role for patents is clearly identified: to increase incentives to innovate but also to mitigate the specific coordination difficulties linked to collective invention.

Contrary to the classical perception where only incentives seem to prevail, shifting to a knowledge-based framework enables to put the emphasis on the role of patents to resolve coordination failures. In most cases patents are used in order to improve interactions among the stakeholders of the innovation process. They enable firms to signal competences, to sell technologies, to enter into cross-licensing agreements, to collaborate, to form innovation networks, etc. Patents are here essential structuring elements of collective innovations.

To stress the importance of this role of coordination, we use the framework built by Callon (1999), who distinguishes two distinct phases of the innovation process: An emerging phase and a stabilised phase. Whereas in stabilised situation knowledge is easily reproducible and the primary role of patents is therefore to protect inventors from imitation, in emerging phases it is the opposite. Knowledge is sticky, market perspectives are uncertain, players in the field are unknown. In such emerging frameworks firms tend to use patents not to exclude other firms but to "include" them, i.e. to find collaborators, suppliers, customers, financers, etc. This role of coordination of the patent system is made all the more relevant that the technology is complex (Kingston, 2001) and the knowledge base tacit.

Considering the specificities of knowledge-based economics therefore underlines new issues when dealing with the role of patents. We are able to stress a new role for the patent system - to ease the coordination among the actors involved in innovation- but there are also new problems that patents may raise for society. In opposition to social costs identified within the traditional approach, which are essentially of a static nature (monopoly deadweight loss), our work emphasises the dynamic inefficiencies that patents can generate, such as the locking of promising technological trajectories.

The next section stresses the specificities of a knowledge-based economy. Specifically, it focuses on the distinction between emerging and stabilised phases and between complex and simple technologies. The third section analyses the role of patents, mainly showing that this instrument has important properties of coordination of the innovation activities. The fourth section investigates the private and social costs of patent whether we stand in the traditional or in the knowledge-based framework. Finally the last section of the paper stresses sectoral specificities with regard to patent strategies. We develop the polar cases of pharmaceuticals, software, biotechnologies and semi-conductors. An important conclusion of this paper is the diversity of role of the patent system. The use of patent is so different among industries that

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also stress that firms place greater value on other means of protection, such as secrecy, lead time, complementary with protected assets, etc., than on patents. These conclusions are robust in the sense that they apply to many countries, industries and time frames.

one should not speak of a unique patent system, but of one in pharmaceuticals, one in chemistry, one in electronics, etc.

2. Rethinking the theoretical framework: Towards a knowledge-based approach

With respect to the role of the patent system, new perspectives arise from the theoretical works on the nature of knowledge and of the innovation process. This stream of literature, inspired by the evolutionary approach of Nelson and Winter (1982), introduces new essential dimensions to comprehend the present debate on intellectual protection. An important issue, that has been widely neglected to date, deals with the distinction between emerging and stabilised phases of innovation (Callon, 1999). This distinction encompasses the tacit vs. codified dimension but cannot be limited to it. Another important issue deals with the difference between complex and simple technologies. The crossing of those two dimensions allows us to distinguish heterogeneous contexts of innovation in which patents have very different roles.

2.1 The need for coordination in the rise of technological trajectories

Winter (1993), while recognising that the patent system can increase incentives to innovate, suggests that intellectual property rights may not lead automatically to a more efficient situation. In particular, he underlines the fact that inefficiencies might especially occur during the very first phases of the innovation process. When a pool of innovators explores a new trajectory, aggressive patent strategies might block the slow build-up of a common base of knowledge required for the development of such a trajectory.

This argument developed by Winter refers to an essential aspect that has been underestimated by Arrow (1962): the exploration of innovation development conditions. In order to underline the dilemma between incentives and diffusion, Arrow simplified the innovation process to a two phase process: invention and then diffusion of the invention. All the aspects related to the complex dynamics linked to the genesis of the innovation were neglected thus reducing innovation to a static two step game.

During the first step of the creation of technological trajectories, the traditional arrovian framework underestimates the need for common knowledge between actors. For Arrow, the knowledge producer is a single individual. Nothing is said about any need for external knowledge required to invent, nor about any community of agents that would help throughout the process of creation (the so called knowing communities). The solitary hero is therefore the only one who should be able to claim any ownership on his invention. Yet, still according to Arrow, the public good nature of knowledge decreases his incentives to innovate. The dissemination of knowledge is indeed considered here as being isotropic: the diffusion of an innovation is not intended to follow a particular path. The possibility that first inventors are able to choose the individuals, groups or communities with whom they will develop a common knowledge base is not recognized. On the contrary, the inventor is supposed to face anonymous agents who are looking for any opportunity to steal his creation. And this free riding can easily happen since any potential imitator is supposed to be able to reproduce the knowledge at zero cost immediately.

For Callon, this scenario can occur, but only in extreme circumstances, corresponding to stable situations in which languages and competences are already shared among actors of innovation. The traditional framework (non rivalry and non excludability of knowledge) only prevails when the technological trajectories and languages have been developed and shared among individuals and organisations.

Callon (1999) shows that during the first phase of the creation of an innovation, when common languages and schemes do not yet exist, it is the exact opposite that happens. Knowledge in this context is marked by strong rivalry (it is hard to reproduce it outside the local context where the discovery has been made) and strong exclusivity (the invention is linked to the tacit knowledge of the inventor). The inventor is less likely to encounter a problem of free-riding and imitation than a problem of misunderstanding from other actors, leading to his marginalisation (Callon, 1993). In other words, the inventor does not face a problem of leaky knowledge (which would decrease its incentive to invent) but rather a problem of sticky knowledge, which undermines its ability to interact with the other actors of the innovation process. For the actors, it is necessary during the first stages of the construction of a technological trajectory to cooperate, to develop common cognitive grounds and above all to converge on shared objectives. Technological trajectories cannot develop by themselves unless public or semi-public common knowledge ground is defined and created in order to enable the reproduction, enlargement, and development of the first creative ideas.

Hence, the first stages of innovation development are a complex and mostly collective process during which agents need to exchange and cooperate. Yet, this process of collective innovation is jeopardized by two main obstacles that may prevent interactions among agents and knowledge exchanges.

In the first place, innovation generally occurs in an environment of strong uncertainty about the actors, their objectives, their capacities, etc. Collaboration between the different actors of innovation is made difficult by problems of uncertainty and incomplete information. This leads to a massive reduction of exchanges between individuals (Akerlof, 1970). Should the latter not recognize the abilities of potential partners, they will be less prone to engage in a relationship that can be very costly. As uncertainty touches all features of an innovation, it has an important negative impact on the process of collaboration between organisations (Pénin, 2005). To solve this problem of incomplete information, firms may be obliged to adopt strategies of signalling, eventually via the disclosure of previously secret knowledge. Here, the signalling property of patents is essential since it may help firms to form innovation alliances.

Secondly, collective innovation is slowed down by problems linked to knowledge flows. Differences of language, of cognitive models or simply the existence of a tacit dimension implies that knowledge exchanges are difficult. When knowledge is tacit, it is hard to transfer (Cowan and Foray, 1997; Cowan *et al.*, 2000). The same applies to language that can constitute a barrier between different disciplines. And the more heterogeneous are the actors involved in the innovation development, the more relevant those problems of communication and exchanges.

These coordination problems tend to constrain the process of collective innovation, especially during its first stages, when agents and competences are not well known and stabilised. This view stands in sharp contrast with the traditional framework and the theory of knowledge externalities, which considers that once knowledge is created, it is available for anyone to use. Obviously in this simplified framework, there can be no coordination problems.

To sum up, it is the complex dynamics of evolution of technological trajectories that is underestimated by the traditional framework. The main weakness of the Arrow model is to reduce the complexity of technological trajectories to a two phase process. At one extreme, there is one single individual that has a creative idea. At the other end lies a universe where all individuals have the same knowledge and are able to exploit the innovation. This reduction has an advantage: it fixes patents on incentives considerations. But it also has a major weakness. It lessens the needs of coordination between agents, especially during the early stages of the creation of an innovation.

2.2 Heterogeneous industrial contexts and the role of patents

To understand the multiple roles of patents in a knowledge-based economy one cannot limit the analysis to the distinction between emerging and stabilised contexts. A further dimension needs to be taken into account, namely the distinction between complex and simple technologies. This dimension affects firms' patenting strategy at its heart since it deals with the freedom that patent holders' have in the use of their patent rights. The distinction between complex and simple technologies is linked to the difference between the right to exclude infringers – which is the right given by a patent, and the right to use a technology. When a technology is simple those two rights converge, i.e. the patent holder has the right to use the patented invention (this use does not infringe other patents). But when a technology is complex it is possible (and sometimes likely) that those two rights do not correspond, i.e. a patent holder cannot use its invention because by using it, it infringes patents held by other firms. The patent holder must therefore ask permission to other stakeholders before using its invention. Although patents give a right to exclude, in the case of complex technologies they may not give a right to use.

A simple (or discrete) technology can be defined as follows: "A simple product or process is one that can be understood or communicated by one individual" (Roycroft and Kash, 1999, p. 262). With respect to patents the important point is that a simple technology is usually protected by one or by a small number of patents. As explained above, the patent owner can therefore use its right to exclude without taking the risk of being himself excluded. Cases of simple technologies are chemical based technologies. A molecule for instance, is usually protected by one single patent. A pharmaceutical company that has a patent on a molecule can therefore exclude infringers and use its monopoly power over the medicines based upon the protected molecules. Exclusion of rivals is therefore possible here.

Conversely, a complex technology is: "A process or product that cannot be understood in full detail by an individual expert sufficiently to communicate all details of the process or product across time and distance to other experts" (Roycroft and Kash, 1999, p. 262). Complex technologies are usually *multi-components*, i.e. to use the technology one needs to combine different components. Yet, those components may each be patented and the patents held by different owners. This implies that a firm that has a patent over one of the components can only exclude other firms from using the technology but cannot use it itself without infringing patents held by other firms. This situation of lock-in is frequent in electronics, a typical example of sector where technology is usually complex (Grindley and Teece, 1997).

Complex and simple technologies induce very different strategic behaviors with respect to patents. As emphasized by Kingston (2001, p. 408) "[in complex technologies] The motivation for their extensive use of patents is therefore quite different from that of firms in simple technologies. In the latter, the emphasis may be said to be primarily offensive (to prevent others from *using* the invention); in complex technologies it is primarily defensive (to avoid being *denied* the use of an invention)".

To conclude this section, we consider therefore that the essential contribution of knowledge based economics to the comprehension of patents is two-fold:

Firstly, the fundamental distinction between simple and complex technologies clearly suggests that the context in which knowledge is created has an influence on appropriation conditions and on the strategic role of patents. For example, in those domains where simple technologies seem to be prevalent (chemicals, pharmaceuticals), where the extent of what can be patented is clearly established, understood and accepted by all concerned actors, the role of patents as an instrument to exclude is strong. On the contrary, in contexts where complex technologies seem to prevail (such as electronics for example), where protectable rights are not clearly established, the role of exclusion of patents tends to be weakened since firms cannot exclude without taking the risk of being excluded themselves.

Secondly, the knowledge-based literature stresses the important needs of coordination of the actors in the first stages of the innovation process. In emerging phases, the need to build common knowledge base is strong and therefore strategies of collaborations tend to overcome strategies of exclusion. As soon as innovations become more mature and situations are stabilised, languages are shared, the importance of patents as an instrument of exclusion increases. It comes out of this analysis that the role of patents is highly dependent on contexts and on the evolution of specific industrial sectors. In mature sectors where the technology is stable and coordination already ensured, actors will tend to favour a traditional patent strategy, while in emerging sectors, an offensive use of patents based mostly on exclusion may have devastating effects.

Figure 1: Different role for patents according to industrial contexts

	Simple (discrete) technologies	**Complex (overlapping) technologies**
Emerging situation	1 Use of exclusion **strong** Use of coordination **strong**	2 Use of exclusion **weak** Use of coordination **strong**
Stabilised situation	3 Use of exclusion **strong** Use of coordination **weak**	4 Use of exclusion **strong** Use of coordination **strong**

Crossing those two dimensions allows defining very different industrial contexts, in which the role of patents differs strongly. To illustrate this point we insist in section 5 on sectoral diversity with respect to patent strategies. We develop the specific cases of pharmaceuticals, software, biotechnologies and semi-conductors. Those cases correspond to situations extremely diverse with respect to the exclusion/coordination dimension. The idea stressed above is that this sectoral diversity can be explained by the nature of the technology and the heterogeneous evolution of the sectors.

Even though such an exercise is always subject to caution and can never take into account the diversity of real situation, one can make the following attempt of classification: Pharmaceuticals, corresponds clearly to the third case: stabilised situation with simple technology induces a traditional use of patents mainly based on exclusion strategies. Conversely, electronics is closer to the fourth case: stabilised industry with complex technology makes equally important the role of exclusion and of coordination. Biotech is somewhere in between the first and the second case. The sector being still emerging, firms have strong need of coordination. Finally, software would correspond to the second case: an emerging sector with complex technology. The need of coordination explains the free-libre open source software movement, which tries to mitigate the potential devastating effects of traditional patent behaviours and to ease the coordination in the development of software.

3. The role of patents as instruments of coordination

As discussed in the previous section, in the renewed framework proposed by knowledge-based economics, patents are not instruments solely dedicated to exclude competitors. This enlargement of the role of patents allows a better understanding of their double nature: they are simultaneously instruments to solve appropriation and coordination failures. Patents contribute to facilitate interactions among actors in the innovation process because they gather two important properties: They simultaneously diffuse and protect knowledge. Patents can therefore ease interactions among the actors of innovation at two levels: (i) They facilitate technology transfer through the exchange of licenses on a market for technologies; and (ii) They favour collaborations among heterogeneous organisations. To understand this point it is necessary to remind the two fundamental properties of a patent:

- First, a patent offers protection to its owner. It allows him to exclude potential imitators to use the patented technology.
- Second, a patent discloses knowledge within the economy. When an innovation is patented, its description is released to the general public generally 18 months later. In addition to the technical information contained in patent databases, the different actors that took part in the development process are listed. A patent application entails therefore the disclosure of the knowledge underlying the invention. This property of knowledge disclosure implies that patents can help to signal competences to other agents. A patent can be a way for potential partners to identify each other in a context where the multiplicity of contacts and information make contacts difficult (Pénin, 2005).

The combination of these two properties –protection and disclosure of knowledge, makes patents a central instrument to ensure coordination of the innovation activities:

Patents facilitate technology transfers. Patents contribute to the creation of a market for technology (even though this market is far from being perfect). It is indeed only the combination of the two properties of protection and knowledge disclosure that make a market of technologies workable. On the one hand the disclosure of knowledge allows technology seller to advertise its product and on the other hand the protection granted by the patent system prevent free riding. Paradoxically, patents may thus favour the circulation of knowledge by helping to solve the Arrow paradox (1962). Furthermore it is important to stress that within this framework patents may also help the transfer of tacit knowledge and not only of highly codified knowledge. Licensing contracts often include specific arrangements that include the transfer of tacit knowledge. As underlined by Foray (2004, p. 136) “Patents create transferable rights and can therefore help to structure a complex transaction that also concerns unpatented knowledge”.

Thanks to their support to the formation of a technology market, patents induce a better division of labour and allow each firm to specialise where she is the most efficient. This market for knowledge also induce a better distribution of the technologies, ensuring that innovation are used by those who are the most capable to generate value from them. Empirically, Arora and Fosfuri (2000), and Arora, Fosfuri and Gambardella (2002) have evaluated that the volume of transactions concerning licensing agreements in fields such as semi conductors, biotechnology, electronics and the chemical industry is important and in some cases superior to the internal investments in R&D by the firms themselves.

Very often the exchange of technology takes the form of a barter. Here patents are used as bargaining chips, in a defensive way in order to acquire the right to use specific technologies, to allow the access to an otherwise locked market by exchanging patents (Levin *et al.*, 1987; Grindley et Teece, 1997; Cohen *et al.*, 2000; Rivette et Kline, 2000). For instance, in sector where technologies are complex, i.e. an innovation combines several technologies and thus its implementation requires the assemblage of several overlapping patents, it is likely that the patent held by one individual infringes several other patents and reciprocally. Cross licensing in such cases can be a solution. In this situation the exchange of patents is a way to clear the rights and to enable continuing exploiting a complex technology[3]. Such bargaining techniques have been emphasised by many empirical studies that all confirm that with respect to patent there is huge differences between sectors (Hall and Ziedonis, 2001; Lanjouw and Schankerman, 2001; Somaya, 2003; Harhoff and Reitzig, 2004).

Patents facilitate collaboration. More than a defensive tool aimed at protecting against legal attacks or negotiating better licensing agreements, patents can also be used in an explicitly cooperative logic. For isolated actors that need to develop collaborations, a patent can be a way to signal the abilities of the owner and to negotiate partnership agreements. In this case, patents intervene fairly early in the innovation process and their role goes beyond a mere perspective of allocation of existing resources. They clearly help to structure collective mode of knowledge creation. During the process of collaboration between different organisations, we distinguish several steps during which a patent can help: firstly, as stated before, in the early stages of collaboration, patents can allow the actors to signal their competences, thus mitigating the problems of incomplete information and facilitating the search of a partner. It also tends to reduce the risks linked to cooperation due to free riding by one of the partners (Ordover, 1991), therefore increasing the incentives to participate in the venture. Patents can also play a key role during the determination of the collaboration modalities. In such situations, patents constitute a way to evaluate the abilities of each partner, and above that, to backup their claims. Patents will therefore influence bargaining power during inter-organisation collaborations. Similarly, during the negotiations they provide a legal security

[3] Von Hippel (1988, p. 53) describes the following situation : “Firm A's corporate patent department will wait to be notified by attorneys from firm B that it is suspected that A's activities are infringing B's patents. Because possibly germane patents and their associated claims are so numerous, it is in practice usually impossible for firm A – or firm B – to evaluate firm B's claims on their merits. Firm A therefore responds - and this is the true defensive value of patents in industry – by sending B copies of « a pound or two » of its possible germane patents with the suggestion that, although it is quite sure it is not infringing B, its examination shows that B is in fact probably infringing A. The usual result is cross licensing, with a modest fee possibly being paid by one side or the other. Who pays, it is important to note, is determined at least as much by the contenders' relative willingness to pay to avoid the expense and bother of a court fight as it is by the merits of the particular case.”

which also eases the settlement of an agreement. Finally, all along the collaboration, patents can assist heterogeneous partners as a depositary of a common language that can be understood by many. Patents can therefore be a prerequisite to bring together actors around a common project.

To conclude, patents represent much more than just a right to exclude. As stated by Hall and Ziedonis (2001, p. 104):

> "Instead of being driven by a desire to win strong legal rights to a stand alone price, these firms are driven by broader motives […] The classical role of patents seems to be dominated by this broader use of patents as "legal bargaining chips" that enable the firms to avoid being excluded in a particular field of use, to obtain more favourable terms to their licensing agreements, to safe guard against costly patent litigation or to gain access to external technologies or more favourable terms of trade".

In parallel to the traditional role of patents as a tool of exclusion we see an equally important second role emerging: to ensure the coordination between actors of innovation. From the vision of industrial property aimed at rewarding the independent innovator, we end up with a conception of industrial property as a structuring element of collective innovation. Yet, this new role raises also new questions. Within a knowledge based framework one can put forward new risks of inefficiencies of the patent system.

4. Patents and social welfare in a knowledge-based economy

The traditional approach emphasises the trade-off between the dynamic social efficiency of the patent system versus its static inefficiency. Within this framework the benefits of the patent system appear mostly on the long run as patents increase incentives to innovate, whereas the costs tend to materialise on the short run. Following this approach, social costs of the patent system are of two types: a temporary monopoly deadweight loss is generated due to the monopoly power held by the patent owner, and patents can create several distortions linked to phenomena of patent races (see figure 2 below).

Figure 2: Costs and benefits (private and public) of patents in the Arrow model (inspired by Lévèque and Menière (2003)):

	Private (for the innovator)	**Public** (for the society)
Benefits	- Limited monopoly power	- Knowledge spillovers - Higher incentives to innovate
Costs	- legal costs of patent - Knowledge disclosure (eases imitation)	- Patent races - Monopoly deadweight loss

Conversely, the knowledge based approach stresses the potential dynamic inefficiencies of the patent system. Within this framework one can put forward three main sources of social inefficiencies on the long run:

First, the multiplication of ownership rights in a specific domain can lead to what Heller and Eisenberg have described as "a tragedy of the anti-commons", an expression that relies on the notion of tragedy of the commons stressed by Hardin (1968). As stated by this biologist, the lack of property rights on a common good can lead, if the good is used above its regenerative capacities, to its destruction. The idea of the tragedy of the anti-commons fosters on the exact reverse problem. In the case of complementary goods there is a risk of suboptimal use of resources linked to the addition of monopoly situations that dramatically increases transaction costs (and triggers a problem of multiple marginalisations). These situations can lead to promising technological trajectories that are artificially stopped, while less socially desirable technologies can finally impose themselves only because of fortunate patent strategy.

In the same vein, patent owner strategies can largely influence the choice of a technological trajectory due to the existence of network externalities in the adoption of a technology (Arthur, 1989). During the early stages of an innovation, the choice of pioneers can have very long term impacts on the industry. The issue raised here is, among others, about standards and about lock-in on suboptimal technologies. Indeed the selection of the dominant standard can be affected by the patenting strategies of the early actors. A firm that chooses to over protect its industrial property runs the risk of seeing a competing technology win the market. Such network effects can explain why in some situations, firms prefer to reveal some of their knowledge to competitors (Pénin, 2007). Well known examples of such orientations to socially suboptimal standards are legion (David 1985, Dalle 1995; Corbel, 2003a). Here, the risk is therefore that patent choices of pioneers lead to lock-in on sub-optimal technologies.

Figure 3: Costs and benefits (private and public) of patents in a knowledge based economy

	Private (for the innovator)	**Public** (for the society)
Benefits	- Signalling - Bargaining power - Access to new technologies - Collaborations	- Incentives and knowledge spillovers - Ensure coordination - Structure collective innovation
Costs	- Legal costs of patent	- Anticommons - Collusion and barriers to entry - Lock-in on sub optimal technologies

Finally, a third risk is that patents participate to the erection of strong barriers to entry, thus reducing competition and inducing social inefficiencies in the long run. Corbel (2003b) shows, for instance, how patents are often used as instruments of co-opetition: Firms use patents to cooperate with incumbents (by cross-licensing their patents for instance) but to exclude potential entrants. Cooperation (or even collusion) between established firms can indeed lead to the creation of a protective nest for such firms excluding any external competitors which would not have enough patents to be part of cross-licensing agreements. Cross-licensing practices in the semi-conductor industry reflect the ambiguous role of patents between cooperation and exclusion. For the established firms that already own an important patent portfolio, cross licensing is a way to collaborate with the other incumbents. But for external firms that could enter the market, these practices tend to create important barriers and therefore to prevent their entrance. This in turn slows-down the emergence of novelty and path-breaking practices, inducing therefore some risks for the pace of innovation of the sector in the long run.

5. Between exclusion and coordination: important industrial diversities

5.1 Pharmaceutical industry: exclusion remains the norm

The pharmaceutical industry remains deeply anchored into the traditional view of patents. Firms in this sector tend to predominantly use patents as a means of exclusion of potential imitators. Also, patents have a strong incentive role. Most privately funded research would stall without it. These points have been confirmed by all the empirical studies on this sector (Mansfield *and al.*, 1981; Mansfield, 1986; Levin *and al.*, 1987; Arundel and Kabla, 1998; Cohen *and al.*, 2000; FTC, 2003)[4]. This particularity of pharmaceuticals can easily be explained.

First, innovation in the pharmaceutical sector is a long, difficult and expensive journey[5]. Second point, contrary to other industries where the costs of imitation are often as high as the costs of initial creation, in pharmaceuticals the identical reproduction of a drug is fairly simple and cheap. Most of the knowledge embedded in drugs is highly codified as they are linked to chemical formulas. Competitors can simply analyze the chemical composition of a specific drug to make an exact copy, at a lower price since it wouldn't have to include the initial costs of research, testing, etc. When innovation tends to be difficult and expensive and its imitation easy and almost costless, incentives to develop new drugs tend obviously to be very low. That is the very reason why patents are so needed in this industry.

Furthermore, a patent effectively protects the composition of a drug. As technology used tends to be simple, few patents are needed to protect a drug. Medical treatments are based on few molecules (often only one), thus minimising cross-licensing side effects and making patents very effective tools to exclude imitators (Lesko *and al.*, 2000; Mahlich and Roedinger-Schluga, 2001). Furthermore, identification of infringements is easy since the existing actors are well-known. Also in the pharmaceutical sector patents are very difficult to overturn. The reason is that the mechanisms that explain why a drug is effective remain most of the time unknown: New drugs are obtained randomly, through a trial and error process. Their efficacy is demonstrated statistically during clinical trials. This implies, like stated by Von Hippel (1988, p. 53) that: "Potential imitators cannot gain much helpful insights from examining a competitor's patented product". Since new drugs are obtained through the

[4] Levin *et al.* (1987) insist on the fact that in almost all sectors, firms do not consider patents as an appropriate tool to properly secure their innovations. Of all the sectors, only two validate the idea of patents as an appropriate strategy against imitation: the pharmaceutical and petrochemical sectors. Furthermore, based on a sample of 100 firms from 12 industries, Mansfield (1986) showed that during the 1981-1983 period the proportion of innovations that would not have been introduced on the market in case of lack of patenting ability would have been of 65% for pharmaceuticals, whereas it never rises above 30% in the other sectors. On the same issue, the Federal Trade Commission (2003) interviewed a panel of several professionals and public researchers in the pharmaceutical sector. For some of them, the innovation rate in the industry without patents would drop by 60%, whereas for others it would entirely collapse.

[5] A drug creation has to go through many different phases: the discovery of an active compound, the biological testing, the clinical trials, and finally the agreement of local authorities. This process is long, because in general a minimum of 10 years is needed between the first researches on a molecule to the commercialisation of the finished drug. It is uncertain since it is usually considered that out of 10.000 molecules only one effectively becomes a drug (Lesko *et al.*, 2000). And finally, it is expensive, as total costs to create a new drug often reach several million euros.

screening of thousands of molecules, the discovery of “me too drugs” would require the same screening approach, effectively making the overturn of a pharmaceutical patent almost as difficult as the initial patented innovation itself.

To sum up, in the pharmaceutical sector, innovation is costly, pure imitation would be easy in the absence of a patent system and patents effectively prevent imitation (they can hardly be overturned). It is hence obvious to understand why patents are so necessary to provide incentives to invent in this sector.

5.2 Semi-conductors: cross-licensing strategies

The semi conductor industry has grown quickly since its creation in the 1950s’: 16% annually over the past thirty years (Attia *et al.*, 2000). An important modification in this industry appeared in the 1980s’ with the emergence of fabless firms, not owning any production centres. Such actors, that remain exclusively creators of electronic components, outsource entirely their production. Technology in this sector is complex. It is therefore very frequent for a unique invention to be covered by hundreds, if not thousands of different patents held by different firms (Federal Trade Commission, 2003).

As explained earlier, the complex nature of technology in electronics implies that patents tend to be used in a defensive way. The primary purpose of patent application is not to exclude other firms but to prevent being excluded. Firms apply for patents in order to keep the technological field open and to be sure they will be able to access any necessary components. This defensive usage explains the increasing number of patents (applied and granted) in this sector, as the number of patent applications compared to R&D investments has more than doubled since the mid 1980’s (Hall and Ziedonis, 2001; Reitzig, 2003). A process of auto-enforcement has established itself, as the more patents are granted the more firms need patents to protect themselves against counterfeiting accusations. This process generates a pure patent race situation, strengthened even more by the risks of hold-up strategies[6].

The cross-licensing model in the semi conductor industry is almost one century old. Historically it finds its roots into the creation of the radio technology. At the beginning of the last century several companies used to own strong patent rights on this technology and were able to block rival firms without themselves being able to use the technology. As each firms were refusing to grant each other licences on the part they owned, a dead end was created that lasted until 1919. By that time, the pioneers of the electronic industry (Marconi, General Electric, American Telephone and Telegraph (AT&T) and Westinghouse) created the RCA (Radio Corporation of America) and accepted to give it their patents. Any stakeholder was therefore able to build a radio. This historical example participated to the creation of a cooperative model based on cross-licensing that still remains today in electronics (Grindley and Teece, 1997).

In practice, strategies of cross licensing in electronics are sometimes quite original. For instance, as patent portfolios of firms tend to be extensive and large, the identification of all the patents linked to a specific technology is a difficult, if not impossible task. The negotiations of cross-licensing agreements are therefore not generally done on one or several

[6] Hold up strategies consist in suing a rival firm for counterfeiting only after the sued firm has made sunk investments in complementary but needed assets. Such sunk investments place therefore the sued firm in an uneasy position during bargaining, usually obliging it to accept any type of agreements (all the more that he may be threatened by a preliminary injunction, Lanjouw and Lerner, 2001).

identified patents, but on a complete field of use. To free a field of use, all patents linked to it and sometimes also patents that are not already applied for are included into the cross-licensing agreement. Put it otherwise firms license "anonymous" (they don't know exactly which patent is included in the deal) and not yet granted patents.

This model of massive cross-licensing in electronics is not without risks for new entrants in the sector. Should a firm with a weak patent portfolio try to enter this sector, the risk would be high for them not to have sufficient bargaining power and be subject to a hold up as discussed before. As according the Federal Trade Commission (2003), more than half a million patents are owned by 40,000 firms. This patent ticket (Shapiro, 2000) induces a risk of anti-common that could in the end impede the dynamics of the industry (Corbel, 2003b).

5.3 Software: The free-libre open source model to prevent exclusion

Software, as a product, can be considered as a translation in a computer language of a human problematic. The software development process has three main steps. First, the design of the problematic meant to be treated; Second, the writing of the source code, which once compiled will give a binary code comprehensible to the machine (Printz, 1998). The third step is the retroactive loops of trial and error, correction and optimisation of the code.

As stated by Graham and Mowery (2003), "Innovation in software is a cumulative activity, and individual software products frequently build on components from other products". Another fundamental characteristic of software innovation is linked to the speed of technology that is extremely fast. As technology keeps evolving, product life cycles tend to be rather short for any given innovation. The software industry is young and most of the radical evolutions that have taken place have been pulled by hardware innovations. In short, software is based on complex and emerging technologies.

Historically, the software industry has used copyright as opposed to patents as a means of protection. The protection granted by copyright differs from the one granted by patents as the object of protection is not the design but the expression of it (the code). The abstract aspects linked to the very nature of software explain the historical exclusion of this domain from patentability. As underlined by the European Patent Convention, software by itself is not considered as patentable. Yet, the mid 1980's marked the starting point of patents being granted on software. First issued in the USA, software patents have slowly been accepted by different patent offices. But this process of software patents recognition is not trouble free, as demonstrated by the definitive rejection of the European software patents directive by the European Parliament in 2005.

Accepted but criticised in the USA (Federal Trade Commission, 2003), not recognized but granted in Europe, software patents are now a reality, but source of strong resistance from actors of the software sector. As barriers to entry on this market are rather low, investment needs weak (as opposed to other sectors developed in this article such as pharmaceuticals or biotech), and marginal costs of reproduction close to zero, alternative models of software production have been created. This is the case for Free-libre Open Source Software (Foray, Zimmerman, 2001), a model of software creation and diffusion that insists more on the benefits of cooperation and diffusion than exclusion and control. In line with our theoretical analysis, this model emphasises the fact that with respect to complex and emerging technologies, the needs of coordination and collaboration overcome the needs of exclusion.

The FLOSS model in software stresses an original use of intellectual property rights, which within this framework are not dedicated to exclusion, but are rather used in a “copyleft” way, to prevent exclusion. Like copyright has been turned to copyleft, patents can be used in such a way as to prevent appropriation of a technology and of its subsequent improvements (Pénin and Wack, 2008). This original use of the patent system is especially appealing in the case of upstream inventions, such as research tools in modern biology, which must remain easily available to foster the emergence of downstream applications.

5.4 Biotechnologies: the case of ambivalence

Biotechnologies can be considered as an emerging, non-stabilized sector, still imbued of legal uncertainties (Coriat and Orsi, 2002). Most of the actors in this industry are balanced between the use of patents to exclude and to include. For this industry, patents seem both to secure investments by protecting inventions and to ease collaboration and interactions between the actors.

The birth of biotechnology is generally associated to the 1980 US Supreme Court decision of Diamond vs. Chakrabarty which recognized the patentability of living organisms. An event that, by itself, demonstrates how sensitive this sector is with regards to patents. Most of the firms in this sector are young, small, and focus essentially on basic research. Such firms could hardly survive without patents as the latter usually represent the only tangible good that can be of value to investors or potential partners. For such small structures, the protection granted by patents plays an essential role since there is no alternative means of protection.

These observations are in accordance with many empirical studies in this sector, which consider patents as pure means of exclusion. But this should not be generalized. As stated by Thumm (2001), innovation in biotechnology is typically a collective process based on a heterogeneous network of organisations (Start-ups, big pharmaceutical firms, public laboratories, etc.). As isolated actors rarely own the financial and scientific abilities to lead a project entirely to its conclusion (including commercialisation), collaborations in the sector are often inevitable (Powell, 1996). In 1998, collaboration agreements signed between biotechnologies and pharmaceutical firms represented 30% of the total collaboration agreements signed in all of the industries (Hagedoorn, 2002; 2003). Within this process, as a competence signal and as a means of protection, patents are essential tools to ease the transfer of technologies and facilitate the collaboration between biotechnology and pharmaceuticals.

In short, few biotech firms, although they wished to, can afford using patents to exclude. The basic need of those firms is rather to “include” stakeholders, to find partners, financers, etc. The strong implication of the public sector in this domain also supports this ambivalence in terms of usage of patents. As many biotechnology firms are created (at least jointly) by public researchers, certain academic habits tend to remain, such as publications for instance (Dasgupta and David, 1994). Many researchers are still reluctant to the idea of controlling knowledge dissemination and excluding some people from using knowledge. In this spirit, some initiatives to use patents to preserve the freedom of a technology, like the FLOSS movement in software, are emerging in life sciences (Pénin and Wack, 2008).

Overall in biotechnology the role of patents therefore swing from exclusion to coordination. In a sense, in this domain patents are used as instrument of co-opetition because they serve simultaneously to exclude and to “include”. This point was recently emphasized by Bureth *et* *al.* (2007) and Bureth and Pénin (2008) in the case of genetically engineered vaccines. They show that the development of genetically engineered vaccines can be decomposed into three broad and relatively autonomous modules (antigen, vector, and adjuvant). Producing a vaccine requires combining one element from each module. Patents are essential to ensure the integration of the different modules at the research stage, and thereafter to industrialize the product. As such, patents become architectural elements of modular innovations, conveying distributed entrepreneurial incentives. In other words, Bureth et al. propose a vision of patents as devices of co-opetition. On the one hand patents allow their owners to exclude imitators within each module. On the other hand patents improve the interactions and the collaborations among the different modules.

6. Conclusion

This work aimed at proposing a new framework to understand the role of patents in a knowledge-based economy. A patent is not a tool dedicated only to exclude potential imitators. It is also meant to facilitate coordination among the actors of an industry. This point has been emphasised by recent works in the field of innovation and knowledge (Mazzoleni and Nelson, 1998; Jaffe, 2000) but has largely been under estimated in the "traditional" economic literature.

We have first stressed that the distinctions among simple and complex technologies and among stabilised and emerging contexts define heterogeneous frameworks in which patents have different functions. We have then showed that when we enlarge our analysis to knowledge based economy the social and private costs and benefits of patents change. While the traditional view insist on the dynamic efficiency of patents versus their static inefficiency, our work put forward several reasons why patents may entail dynamic inefficiency. We specifically insist on the role patents have to shape technological trajectories and therefore to orient technological progress in some domains rather than in others.

To illustrate the different role of patents in heterogeneous contexts we have described the situation in four industries in which patents play very different functions. The pharmaceutical industry illustrates the arrovian patent paradigm: Patents are central to appropriate innovation, to exclude imitators and to provide incentives to invest in R&D. In the electronic industry patents are mainly used in a defensive way, to keep fields open by cross licensing. In the software industry many actors are afraid of the consequences of aggressive patent strategies and alternative models have been developed, based on openness and collaboration. Finally, in the biotech sector patents play an ambivalent role, half among exclusion and coordination.

This view of patents as being an instrument central to resolve coordination problems at early stages of technology emergence has many political implications. Here are three "hot spot" at the core of the discussions around the patent system in Europe and elsewhere and on which our work may bring a new light: The role of patents in open science; the cost of patent application and the language in which patents are written.

Science in Europe has shifted from a classical linear model - in which the main activity of scientist is to publish their work in scientific journals, to a model in which scientists missions are widened. The main change deals with the industrial valorisation of research, topic on which scientists are required to be more involved. Within this new model, public research organisations are now almost systematically patenting their research (Mowery *et al.*, 2001, Mazzoleni and Sampat, 2002; Mowery and Ziedonis, 2002). This patenting activity has generated a tremendous number of critics since many observers fear that it will decrease the rate of production and the availability of basic knowledge (Nelson, 2004). While we agree with most of the doubts that have accompanied this systematic patenting of university research, our work suggests that this trend may not be so harmful for the availability of basic research. Used in a logic of coordination and not of exclusion patents may indeed help to increase the dissemination of basic research undertaken within public research organisation labs. At least, they can help to include public research centres within industrial networks.

The cost for actors to patent their research is also vividly discussed nowadays in Europe. The main concern here is that patents are too costly, which would deter small actors to use this instrument. Many political decisions are therefore trying to decrease the cost to apply for patents at least for small companies. Whereas, without doubts encouraging small firms to protect their innovation is necessary, our work contributes to raise one likely secondary effect that may be induced by the reduction of the cost to apply to patents. We showed here that patents are also a tool to signal competences to potential financers, partners, etc. The cost of the instrument is central to this signalling dimension. Shall patents become free it will strongly impede their signalling properties, thus diminishing their coordination potential. This is made especially obvious in the US case, where the proliferation of low quality patents is endangering the pace of innovation (Jaffe and Lerner, 2004).

Finally, a last implication deals with the language in which patents must be written. While it is obvious that to translate patents in every language in Europe or in the world generates huge costs, it is important to keep in mind the central merit of this property of the patent system. It allows a wide dissemination of patented knowledge. Shall this property be given up it must be feared that the patent system will loose one of its main positive effects, which is to contribute to the construction of a stock of knowledge easily available from all around the world.

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