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Patents and innovation: Are the brakes broken, or how to restore patents' dynamic efficiency?

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Abstract

The standard view of patents emphasizes their dynamic efficiency. It considers that, by providing firms with incentives to invest in R&D and to disclose their knowledge, patents encourage innovation and increase social welfare in the long run. Yet, a growing body of literature opposes this view and asks for patent reform or even for the abolition of the patent system. In this work, which reviews the most recent literature on patents, we show that patents can have a negative impact on the dynamics of innovation. This is not due to some intrinsic properties of the patent system but to some of its recent evolutions which mean that, nowadays, too many patents are granted and that patent information is bad. The combination of those two elements explains most of the problems induced by modern patent systems such as hold-up (patent trolls), anti-commons (royalty stacking), and high transaction costs in markets for technology. We conclude by showing that realistic reforms can solve those problems and ensure that the patent system becomes again an instrument of dynamic efficiency.

Keywords: Incentives, Patent, innovation policy, hold-up, trolls, anti-commons, markets for technology.

"[*Patents] are, in the conditions of the perennial gale, incidents, often unavoidable incidents, of a long-run process of expansion which they protect rather than impede. There is no more of paradox in this than there is in saying that motorcars are traveling faster than they otherwise would because they are provided with brakes*"

(J.A. Schumpeter, CSD, 1942)

"*Our efforts at patent reform only went about halfway to where we need to go and what we need to do is pull together additional stakeholders and see if we can build some additional consensus on smarter patent laws*"

(President Obama, February 14, 2013)

1. Introduction: The "second best" view in question

As emphasized by Schumpeter's famous quotation which heads this text, standard economic theory considers that, the same way brakes encourage drivers to accelerate and thus increase car speeds, patents encourage firms to invest in R&D and contribute thereby to increasing innovation, growth and social welfare. This vision focuses on the dynamic, long run properties of the patent system.

Patents not only increase incentives to innovate, they also help disseminate technical knowledge within the economy (since the description of the patented invention is automatically published). In other words, the patent instrument provides an elegant solution to the Arrow dilemma (1962), which highlights the difficulty to achieve both optimal incentives to produce knowledge and optimal level of dissemination of the produced knowledge[1]. In addition, works on open innovation have also emphasized the fact that patents facilitate collaborations and market interactions between firms (Arora *et al.*, 2001; Chesbrough, 2003). Patents have therefore a triple incentive role:

[1] In his seminal paper Arrow (1962) concluded that: "*To sum up, we expect a free enterprise economy to under invest in invention and research (as compared with an ideal) because it is risky, because the product can be appropriated only to a limited extent and because of increasing returns in use… Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an under-utilization of that information as compared with an ideal allocation*".

(1) They induce firms to invest in R&D and to innovate (Kitch, 1977)[2];

(2) They induce firms to disclose their inventions (not to keep them secret) (Encaoua *et al.*, 2006);

(3) They induce firms to interact and to practice open innovation (Chesbrough, 2003).

In exchange for these services, the standard vision insists only on the deadweight loss induced by patents in the short term. Due to the monopolistic distortions patents contribute to create they do not lead to a "first best" but only a "second best"[3]. Patents lead to creating inefficiency in the short term but are source of efficiency in the long term.

If this vision of patents has the merit of consistency and simplicity, a growing number of researchers tend to oppose it more or less frontally (Kingston, 2001; Bessen and Meurer, 2008; Hilaire-Pérez *et al.*, 2013)[4] and call for either major reforms of the system or even for its abolition[5]. The main argument put forward by these opponents is that, in opposition to the claims made by the standard theory, patents may sometimes negatively impact the dynamics of innovation and thus have consequences far beyond the short-term. For example, Jaffe and Lerner (2004) explain that: "The United States patent system has become sand rather than lubricant in

[2] Taking the Schumpeterian distinction between invention and innovation, it is important to recall that patents provide incentives not only to invent (to invest in R&D) but also to innovate, i.e. to invest (in production, distribution, marketing, et.) in order to give economic value to an invention. Also, they provide incentives to prospect in order to find profitable markets for an invention (Kitch, 1977).

[3] Another important limit of patents put forward by standard analysis, but often forgotten in economic textbooks, is that patents, in some contexts, do not provide enough incentives to innovate. Patents provide innovators with a monopoly profit whereas the reward which would maximize social surplus equals the social benefits induced by the innovation (Shavell and Ypersele, 2001). In other words, patents do not allow the aligning of private incentives of firms with social incentives, i.e. the ones which would maximize social surplus. Thus, it is possible that patents do not induce firms to invest in R&D, because the expected private value of the innovation is low (due to an absence of a market demand for instance), although the social value of the innovation is high. This is typically the case of orphan diseases.

[4] Bessen and Meurer (2008) conducted a review of the literature on the link between patents and incentives and concluded that: "the evidence paints a rather mixed picture. In some industries, such as pharmaceuticals, patents provide strong positive incentives to invest in innovation. But in many other industries, perhaps most, patents fail to perform like property and they may actually discourage innovation" (2008, p.2). Similarly, a recent special issue of the *Revue Economique* published in 2013 focused on « innovation without patent » and questioned seriously the role of patents as an instrument to encourage innovation.

[5] Let us quote simply the three most emblematic books on this issue: « *Innovation and Its Discontents: How Our Broken Patent System Is Endangering Innovation and Progress, and What to Do About It* », Jaffe and Lerner (2004); « *Against Intellectual Monopoly* », Boldrin and Levine (2008) ; « *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk* », Bessen and Meurer (2009). It is to be noted that these books focus all three on the US context.

the wheels of American progress". According to these authors, in many cases the patent system today harms inventors rather than helps and encourages them.

How to explain this difference between the standard view of the patent system and the way it is actually working today according to many experts? The present article attempts to answer this question by reviewing the most recent literature on the role of patents in the innovative process. We show that, contrary to the classical analysis that highlights only static costs, patents may also impact the dynamics of innovation, and hence have enduring long term effects, by promoting negative, "hold-up" like, strategic behaviors ("trolling") (Shapiro, 2001), helping create situations of anti-commons ("royalty stacking") (David, 2011), and introducing transaction costs in the sequential process of innovation (Scotchmer, 1991). However, we also show that these adverse effects of patents come from recent evolutions of the patent system rather than from its intrinsic properties. In particular, today, too many patents are granted and patent information is bad, thus creating what Menell and Meurer (2013) call problems of "notice failure". The combination of these two elements explains most of the problems posed by the patent system. Yet, we argue that realistic patent reforms can solve those problems.

The paper is divided as follows: In Section 2 we review the sources of patents' dynamic efficiency. We emphasize that if patents accelerate the dynamics of innovation it is mostly due to their support to open innovation and, in particular, markets for technology. In Section 3 we show that patents can, in some contexts, have a negative impact on the innovation process. In the fourth part we examine the causes of this dynamic inefficiency in order to, in the last section, suggest elements of patent reform that could, using Schumpeter's metaphor, contribute to fixing the engine's brakes, i.e. restoring patents' dynamic efficiency.

2. Patents' dynamic efficiency: Distinguishing the true from the false

2.1 Incentives for whom? Manufacturing versus technological firms

Standard theory emphasizes the positive impact of patents on firms' incentives to invest in R&D. Yet, most empirical studies question this incentive effect for manufacturing companies, which often prefer to rely on other strategies such as secrecy, technological advance or complementarity

with other assets (sales force, production capacity, brand or distribution network) (Levin *et al.*, 1987; Sakakibara and Branstetter, 2001; Cohen *et al.*, 2002; Lerner, 2002)[6]. This suggests that the effect of patents on manufacturing firms' incentives to invest in R&D is low. Mansfield (1986) even highlighted that, should the patent system be dropped, most manufacturing companies in almost all sectors (pharmaceuticals being the main exception to this result) would continue to invest as much in R&D as they do with patents.

Several factors explain this lack of correlation between patents and incentives to innovate for manufacturing companies. A patent is expensive and its efficacy is not certain. Many patented inventions have close substitutes and can be bypassed relatively easily and quickly. Also, in areas where the technology is complex, a product may be the subject of several overlapping patents, thus inducing problems of freedom to operate. In this case, patents are mostly used in a defensive way. It is therefore rare that a patent gives its owner a significant market power over a manufacturing product. The only exception here remains the pharmaceutical industry in which it is well known that innovators can often charge prices well above the marginal cost of patented new drugs.

To understand the incentive role of the patent system, we therefore argue that it is essential to distinguish between manufacturing and technological firms. The former possess many complementary assets to protect their technologies and, moreover, are not concerned with the direct sale of technology but with the sale of manufactured products in which they incorporate their inventions. Hence, it is not surprising that patents play only a marginal incentive role for these companies, which can mobilize alternative protection strategies and, above all, rely on the protection ensured by their complementary assets. However, this is not generally true for technology firms whose business model involves selling inventions and technologies directly. For these firms a patent is usually the only valuable asset and the only instrument of protection (especially when the knowledge base is largely codified) and therefore it becomes essential. Without the patent system it is likely that most technological firms would stop performing R&D. This argument is linked to the point made below on the link between patents and markets for

[6] Lerner (2009, p. 347) explicitly acknowledged this point by stating that: "the lack of a positive impact of strengthening of patent protection on innovation is a puzzling result. It runs against our intuition as economists that incentives affect behavior".

technology (see Section 2.2). Yet, most large scale studies focus primarily on manufacturing companies (for instance the famous "Yale survey", Levin *et al.*, 1987; or "Carnegie Mellon survey", Cohen *et al.*, 2002). It is thus not surprising that these studies conclude that patents have a marginal impact on incentives to perform R&D[7].

2.2 Markets for technology: Licensing and division of innovative labor

If the standard vision of the patent system seems largely inaccurate, especially for manufacturing firms, it does not mean that patents do not have a positive impact on innovation. The main interest of patents for firms is probably to look elsewhere. For instance, the opportunity to sell a license is a crucial element of the patent system because it provides important incentives to perform R&D even for actors who do not want to become suppliers of tangible products (for instance, universities, independent inventors, start-ups, etc.) (Gallini and Winter, 1985). The possibility to sell a license increases the potential economic value of research results and thus increases incentives to undertake it.

Since they both disclose the knowledge underlying the invention and protect this invention, patents contribute to solving the Arrow paradox (1962) and, via the licensing mechanism, encourage markets for technology. Furthermore, a major consequence of markets for technology (Arora *et al.*, 2001) is to promote a vertical division of labor and thus the growth of small specialized firms with strong skills and a greater ability to innovate in a sustainable manner. Without patents, those firms, often called "fabless firms", could hardly exist because they could not sell the knowledge and technologies that they produce.

[7] If the patent system does not increase manufacturing firms' incentives to invest in R&D, one can also question its second role: providing incentives to circulate technical knowledge within the economy thus promoting knowledge cumulative production process. The patent system is indeed a bulwark against secrecy and secrecy is costly to society. For many observers, this disclosure property is the most important fact about the patent system. If it is difficult to completely reject the disclosure role of patents, it is nevertheless important to mention two qualifications: 1) a large number of patented inventions are disclosed precisely because secrecy is difficult to maintain (for instance in the case of product innovations). Would this not be the case, firms would prefer to keep their inventions secret. Hence, one can argue that in many cases the patent system contributes to making public inventions which would have become public anyway (since they are difficult to keep secret); 2) An increasing number of patents are drafted in an unintelligible way (Menell and Meurer, 2013) and there is a huge number of published patents in the world every year. This obviously does not facilitate the analysis and scanning of the patent literature. We shall return on this point in the following sections.

This vision adds therefore issues of vertical integration and boundaries of the firm to the one of incentives to perform R&D (Arora and Merges, 2004). Industrial firms located downstream of a productive sector must decide whether to produce a specialized input internally or to obtain it from an independent upstream supplier. In the standard "Make or Buy" model a contract may motivate the supplier to use its expertise to tailor its product to the needs of the downstream firm. However, such a contract has some limits. It is for instance difficult to know the costs *ex ante* (and therefore the price) of the product; It is also difficult to write and enforce a contract defining the transfer of the technology (free rider and hold-up problem). A well designed patent system can solve the problems of opportunistic behavior and thus reduce transaction costs in the markets for technology. Patents held by upstream firms reduce the risk of hold-up and free-rider behavior on the part of the buyer. Thus, following the approach developed by Arora and Merges (2004), cooperation and division of labor in innovation activities are made possible precisely by the existence of patents[8].

It is worth adding that due to high transaction costs in markets for technology (even when patents are present), new players have emerged recently to reduce these transaction costs and facilitate technology transfers (Benassi and Di Minin, 2009; Dushnitsky and Klueter 2010; Hagiu and Yoffie, 2013). These market intermediaries, patent and technology brokers, are firms (consulting companies) composed of experts in law, policy, economics and finance. Their role is to assist stakeholders in the process of technology transfer. Indeed, in a market where information flows imperfectly, where the value of technology is difficult to assess, where contracts are often very incomplete, technology transactions are risky. In other words, technology intermediaries support markets for technology and, unlike patent trolls (see Section 3.3), with whom they are often confused, they have a positive effect on innovation and the economy (Pénin, 2012).

2.3 Patents as structuring elements of open innovation

As an extension to the former point, a recent literature strand shows that patents may be structuring elements of open innovation (Chesbrough, 2003; Cohendet and Pénin, 2011). Patents allow firms to signal technologies and knowledge, to improve their bargaining positions, to sell

[8] Note that some problems faced by markets for technology have been put forward by Gambardella (2005).

technologies in markets. In particular, patents promote market and non-market interactions between innovative companies:

- As mentioned in Section 2.2, patents promote markets for technology (Arora *et al.*, 2001; Arora and Merges, 2004) and the emergence of technology firms specialized in the production of knowledge which they can then transfer to manufacturing companies.

- More than instruments for ensuring market coordination of innovative activities, patents also intervene earlier in the process of innovation, by fostering collaborations and non-market interactions (Hagedoorn and Ridder, 2012). By enabling firms to signal their expertise to potential partners, protecting these skills and providing a legal framework for negotiations, patents support collective modes of knowledge production such as innovation networks, research consortia, formal and informal collaborations, research joint ventures, etc.

In conclusion, in sharp opposition to traditional teachings, except in a limited number of sectors (of which pharmaceuticals is the perfect example), patents rarely contribute to significantly increasing manufacturing firms' ability to exclude imitators and to enjoy monopoly positions. Rather, the positive aspect of patents in the dynamics of innovation relies mainly on their structuring role of open innovation processes and, in particular, on their support to markets for technology, thus favoring the emergence of independent technology suppliers. Yet, this positive role must be weighed against the possible adverse effects of patents on innovation that have been recently highlighted in the literature.

3. Patents and dynamic inefficiency

Three major sources of dynamic inefficiency linked to patents are discussed in this section: Transaction costs in technology deals (3.1), royalty stacking and anti-commons (3.2), and "hold-up" and patent trolling (3.3).

3.1 The case of sequential innovations

The standard view neglects the question of sequential innovations[9]. Yet, it is now widely accepted that, in many areas, innovation proceeds sequentially, i.e. today's innovations feed tomorrow's innovations. Inventors do not start from scratch but sit on the "shoulders of giants" (Scotchmer, 1991). It is possible to identify several types of sequential innovations (Scotchmer, 2004). For example, firms that undertake applied research must use more upstream and fundamental knowledge. Or they must use and combine different research tools in order to advance their research and develop their products. Or inventors must improve an existing product on which they base their research. In any of these examples there is a sequence since a research in a first step feeds another research in a second step.

A key element in the case of sequential innovations is that first-generation innovations are necessary for second-generation innovations. The latter cannot be created without the former. This raises clearly the question of the accessibility of first-generation innovation and thus the question of the role of patents. How do patents manage to ensure the distribution of profits between the different generations of innovators (Scotchmer, 2004)? The absence of patents or too weak patents, i.e. too easy to circumvent, may offer few incentives to first-generation innovators. Conversely, too strong patents, i.e. too protective, increase the cost of accessing first-generation innovations and therefore may reduce incentives to produce second-generation innovations. Scotchmer (1991) showed that there is no "fine tuning" to the patent system which can solve this dilemma.

[9] More generally, this criticism meets the questions put forward by evolutionary economics. In opposition to standard theory, which neglects the long term effect of the choice of a technology, the evolutionary literature is almost entirely focused on the dynamics of technical progress and on the fact that innovation is a sequential process in which history, i.e. past choices, matters. This literature insists on the fact that innovation follows technological paradigms and trajectories which, once developed, are difficult to reverse (Nelson et Winter, 1982). Innovation is therefore largely path-dependent and initial decisions may soon become irreversible. In this context the risk is therefore that patents interfere in the choice of a technological trajectory and provoke a lock-in on a sub-optimal technology. In particular, the proliferation of patents may block the construction of the common knowledge base which is necessary for the emergence of the new paradigm (Winter, 1993; Freyermuth *et al.*, 2012). This evolutionary view puts forward the importance of past choices and the fact that patents may contribute to guiding the economy on a bad technological trajectory, i.e. selected not due to its technological properties but to reasons that have to do with patents, of which it becomes difficult to deviate.

This analysis stresses that patents, in making it harder to use patented technologies, may hinder the dynamics of innovation. Patent holders may oppose the reuse of their technologies and slow-down technological progress. However, contract friendly people may ask why first-generation inventors, who are perfectly rational and profit maximizers, would refuse to grant licenses to second-generation innovators? It would be more profitable for them to license their technologies and to obtain royalties. Patents should therefore not oppose the reuse of existing technologies, they should not affect the efficiency of the process, but just impact the distribution of profits between the different generations of inventors. Yet, it is possible to object at least three things to this "contract friendly" argument (Menell and Meurer, 2013): 1) high transaction costs may prevent the completion of mutually beneficial transactions (and we will see below that transaction costs, despite the patent system or due to some of its failure, can be high in markets for technology); 2) firms operate in highly uncertain environments and risk aversion can prevent the execution of transactions (the required premium may be too high); and finally 3) the risk of hold-up and patent holders' strategic behaviors (see Section 3.3) may also reduce the incentives for second-generation innovators.

3.2 Anti-commons, royalty stacking and patent pools

The "tragedy of the anti-commons" is somehow a generalization of the previous problem. In sectors where the technology is complex (multi-components) firms must combine several technologies in order to bring a new product on the market. Yet, many of these technologies are patented which forces the innovator to negotiate permission with each patent holder. This leads to an increase in transaction costs and may induce a problem of "royalty stacking", which is to say that the addition of fees for accessing the various components can ultimately make innovation not profitable, thus reducing its diffusion and use. Although individual royalties represent only a small amount, once "stacked" they can become substantial (David, 2011). In particular, the price increase induced by the fragmentation of ownership and the proliferation of patents is due to the well-known principle of multiple marginalization. The proliferation of patents on complementary technologies may thus lead to an under-utilization of these technologies, which explains the use of the term "tragedy of the anti-commons" (Heller and Eisenberg, 1998)[10]. To our knowledge,

[10] The expression "tragedy of the anti-commons" refers to the well-known expression "tragedy of the commons" (Hardin, 1968). Common resources, i.e. non-appropriable but rival resources, may be used too intensively (above their capacity of regeneration) which may lead to their disappearance. In this case, the absence of property rights

very few studies managed to measure empirically the anti-commons problem. An exception is the work of Murray and Stern (2007) who, based on patent citations, found a small but significant anti-commons effect. Von Graevenitz *et al.* (2011; 2012) also proposed a method to measure the "patent thicket" and concluded that the problem may be acute in some cases.

Some practices, such as cross-licensing agreements and patent pools, can to some extent allow firms to "navigate the patent thicket" (Shapiro, 2001)[11]. For example, two firms, noting that some of their research programs or some of their inventions are built on intellectual property assets held by the other firm may mutually exchange licenses so as not to interrupt their research and/or to sell their products without risk of being sued for infringement. Cross-licensing is hence a strategy which enables firms to ensure freedom to operate. Cross-licensing agreements may include entire technological fields ("field of use") and even patents not yet filed. These strategies are typical of sectors where technological progress is cumulative and the knowledge base complex, i.e. multi-component (up to hundreds, and sometimes thousands of patents can protect a product), such as electronics, computers and semi-conductors (Grindley and Teece, 1997). Yet, it is important to mention that if cross-licensing practices may constitute an efficient *ex post* strategy to avoid being denied the use of a technology, they also contribute to increasing the proliferation of patents and the risk of anti-commons by encouraging firms to multiply patent applications to protect themselves in case they are accused of infringement (defensive patenting strategies, Grindley and Teece, 1997).

"Patent pools" are also institutions that contribute to restoring to some extent the dynamic efficiency of the patent system. The idea of a patent pool is to gather all the patents which are relevant to use a given technology in a single structure in order to unify the intellectual property related to this invention and thus facilitate its dissemination (Merges, 2001). Users of the invention, instead of having to negotiate with a myriad of patent holders, each in a situation of local monopoly, only have to bargain with a single owner, namely the manager of the patent pool.

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induces a utilization of the resource which is too important as compared to an ideal situation. By symmetry, in the case of the "tragedy of the anti-commons", too many property rights (i.e. the fragmentation of the ownership of a single resource) induces a use of the resource which is too low as compared to the optimum.

[11] Compulsory licensing may also contribute to softening problems of anti-commons. However, this type of licenses is difficult to apply in practice and its use is limited to the case of public health in most countries (Martinez and Guellec, 2004).

This obviously facilitates access to the technology, reduces the number of transactions that have to be handled and, most of all, lowers the price of the technology since patent pools, by unifying property rights, solve the problem of multiple-marginalization.

In sum, patent pools have many advantages for innovators, including limiting the number of licensing agreements and allowing companies to obtain licenses at reasonable prices. Lerner and Tirole (2004) hence showed that social welfare is enhanced by the formation of pools when patents gathered in the pool are more complementary than substitutable. When patents are strictly complementary, patents pools increase both firms' profits and consumers' surplus. Furthermore, they can reduce incentives to invest resources in inefficient duplications, which is also positive for social welfare. Thus, it is easy to understand why, due to the increasing proliferation of patents in certain sectors, which greatly complicates access to technology, patent pools are a growing phenomenon and are likely to continue to develop in the near future. Nowadays we even have examples of firms which form pools of patent pools (den Uijl *et al.*, 2013). However, the formation of patent pools is not free of problems. Companies can sometimes be tempted to use patent pools strategically in order to reduce competition by including into the pool non-essential and rather substitutable patents. In this case, the formation of patent pools can be anti-competitive and reduce social surplus (Lerner and Tirole, 2004; Brenner, 2009; Layne Farrar and Lerner, 2011; Lévêque and Ménière, 2011).

In conclusion, if the problems of "anti-commons" and "royalty stacking" can be serious, we have also seen that there exist ways for firms to mitigate them, by forming patent pools or engaging in cross-licensing agreements. However, it is not certain that these strategies always work successfully and, even if that were the case, it remains that these practices are costly. In a sense they illustrate well the social costs of patents. In the absence of the patent system, resources engaged into patent pools and cross-licensing could be used elsewhere.

3.3 Patents strategic manipulation: Hold-up, "trolls" and standards

A last element overlooked by the standard view is that patents can be used for strategic purposes which, if they increase the private value of patents for their owners, are harmful from a social point of view, in particular because they affect the dynamics of innovation. Specifically,

"trolling" behaviors consist for a company (usually a non-manufacturing firm, also known as NPEs ("non- practicing entities") or PAEs ("patent assertion entities")) in trying to hide some of its patents in order to provoke infringement and to place infringing firms in hold-up situations (Pénin, 2012)[12]. A firm may be trapped in a hold-up situation when it has undertaken sunk investments (for instance when building a new factory, a new production line or implementing a major advertising campaign for the launch of its new product). As it has already invested, the company can hardly stop its activity if it is accused of infringement (sunk investments commit firms over the long term), which puts it in a very uncomfortable position to negotiate licenses on the infringed patents. Patent trolls thus try to provoke hold-up situations by hiding their patents and refusing to grant licenses before potential infringers (usually manufacturing firms) have made sunk investments.

This strategy of "trolling" allows patent holders to capture a share of the value much higher than the intrinsic value of the technology they own (Lemley and Shapiro, 2007; Farrell *et al.*, 2007; Shapiro, 2010). In other words, the value of their technology *ex post*, once it has been infringed, is much higher than its value *ex ante*, if it is not infringed. The most emblematic example of the value of hold-up for a patent holder is the Blackberry case which allowed a small American company (NTP) to obtain $ 612.5 million from the company that invented the Blackberry (RIM). Although the technologies patented by NTP were very far from being worth such a huge amount of money (Magliocca, 2006), RIM was placed in a situation of hold–up, that is to say in a situation where it was no longer possible to go back. This enabled NTP to obtain an indemnification largely superior to what it could have obtained during an *ex ante* negotiation. The prospect of earning a profit much higher than the intrinsic value of their technology may hence encourage patent holders to behave like "trolls", i.e. to try to hide their patents and not to approach manufacturing firms in order to grant them licenses. According to a recent report by the White House (White House patent report, June 4, 2013) disputes caused by trolls tripled between 2011 and 2013 from 29 % of patent litigation in the United States to 62%. According to the

[12] The word troll precisely reflects this dissimulation behavior in order to provoke irreversibility and hold-up. In Scandinavian mythology, trolls are ugly monsters who hide in the forest and wait for merchants to cross the forest in order to rob them. Trolling behavior thus means to delay the attack in order to be sure that merchants are engaged deeply in the forest and cannot go back. Interestingly one can note that patent trolling amounts in a sense to radically hijacking the patent system. The latter was erected precisely to avoid imitation whereas trolls use it in order to be infringed. For a troll a patent has no value if it is not infringed. Trolls' business model is based on infringement. They want to be infringed.

report, in 2012, trolls would have accused of infringement approximately 100,000 companies in the United States.

The problem with trolls is that they have an adverse effect on social welfare (Pénin, 2012). For Reitzig *et al.* (2010), the business model of trolls is based solely on value destruction. Unlike technology brokers who do not hide their patents and whose role is to facilitate transactions in markets for technologies and to support the development of technology firms (see Section 2.2), trolls do not contribute to creating value for society. This point was clearly stated by President Obama who, in a recent speech, claimed: "The folks that you're talking about [PAEs] are a classic example; they don't actually produce anything themselves. They're just trying to essentially leverage and hijack somebody else's ideas and see if they can extort some money out of them" (President Obama, February 14, 2013). Bessen *et al.* (2011) tried to quantify the damage caused by trolls and concluded that: "we find that NPE lawsuits are associated with half a trillion dollars of lost wealth to defendants from 1990 through 2010, mostly from technology companies. Moreover, very little of this loss represents a transfer to small inventors. Instead, it implies reduced innovation incentives and a net loss of social welfare"[13].

But beyond the costs of litigations provoked by trolls, the most disastrous consequence of "trolling" is likely to stem from the deterring effect on innovative firms. Trolls introduce uncertainty on the freedom to operate of innovative firms. Anticipating the encounter with a troll, innovative manufacturing firms may become reluctant to invest in R&D and to bring new products to the market (Pénin, 2012). These reservations may also directly impact technology firms which will find it more difficult to sell their technology to innovative manufacturers. Furthermore, Tucker (2013) shows that patent trolls, by provoking litigations on new technologies, can have a negative effect on the diffusion of these technologies and harm their incremental process of improvement. Indeed, during the trial, legal uncertainty put on the technology is likely to reduce other firms' incentives to develop improvements and complementary products to this technology.

[13] It should be noted that if the problems of hold-up and "trolling" are currently largely specific to the North American case, it is feared that the forthcoming adoption of the European unitary patent will facilitate the emergence of these practices in Europe. Interestingly, a coalition of innovative manufacturing firms (including Google, Microsoft, Apple, Samsung, Yahoo, Intel, etc.) sent, on September 26, 2013, an open letter to EU member countries to warn against this risk.

The strategic manipulation of patents in order to provoke hold-up situations may also occur during the implementation of standards (Tassey, 2000). In areas where the technology is complex, the multi-component nature of technology raises important needs of standardization in order to facilitate compatibility between components and to benefit from network externalities. This is particularly the case for information and communication technology (Maskus and Merill, 2013). Furthermore, for a given standard, some patents are more important than others. They are called essential patents, that is to say patents that are difficult, if not impossible, to circumvent to design and produce products in accordance with the standard (Bekkers *et al.*, 2011). Hence, in the process of establishing a standard, firms which own essential patents may have an interest in concealing them in order to increase their value thereafter, when the standard becomes effective and the patents included in it, essential (Shapiro, 2001; Berger *et al.*, 2012). Yet, again, these attempts to provoke hold-up in the implementation of standards may have a negative effect on manufacturing firms' incentives to invest in R&D and on the diffusion of the standardized technology. To prevent those strategic uses of patents, antitrust authorities and major industrial stakeholders usually try to agree on some shared rules. For instance, firms which take part in the negotiations about a standard usually commit themselves to disclosing patents considered as essential. Also, the licensing of patents essential to the standard is usually operated under conditions that are FRAND ("Fair, Reasonable And Non-Discriminatory") (Lemley and Shapiro 2013).

3.4 Some major differences across sectors: The SSIP hypothesis

As regards the consequences of patents on innovation dynamics, important differences across sectors can be expected. Bah and Le Bas (2011) talk of sectoral systems of intellectual property (SSIP) in order to characterize the fact that the economic impacts of intellectual property, including patents, depend on the sector. In particular, the technological regime underlying industries strongly affects the way companies use their patents (Cohendet and Pénin, 2011). The technological regime of an industry refers to a particular combination of factors specific to the technology used in this sector and which influences the strategy of the actors who operate in the industry (Nelson and Winter, 1982). The technological regime includes several dimensions: high versus low appropriability, tacit versus codified knowledge base, presence or absence of network

effects, modular versus integrated technology, cumulative versus science-based innovation, etc. (Cohendet and Pénin, 2011).

In particular, when it comes to patents, the complex versus simple dimension of the technology is essential. Simple, or discrete, technology is mono-component. There is thus a direct correspondence between the technology and the product sold in the end-market. Problems of freedom to operate are hence not relevant in the case of simple technology and the number of patents in a given sector is reasonable. The emblematic example of a sector where technology is simple is pharmaceuticals where, in general, a molecule leads to a drug and therefore a patent on the molecule provides exclusivity on the drug market. In contrast, a complex technology is multi-component. In order to put a product on the market the innovator must combine a large number of components, each being potentially patented. In this case the issues of freedom to operate are central and the number of patents on a single innovation can be high. The emblematic example of a sector where technology is complex is electronics.

Differences in the technological regime across sectors can thus explain why the standard vision is particularly well suited to pharmaceuticals but much less to other sectors such as electronics, ICT or software, where the complex nature of technologies increases the risk of tragedy of the anti-commons and the possibility of "trolling".

3.5 Intermediary conclusion: Static versus dynamic efficiency

In opposition to the message sent by the standard patent theory, in most industries, optimal patent policy must be the outcome of an arbitrage not between static inefficiency and dynamic efficiency, but between static and dynamic inefficiency, because patents can also hinder innovation dynamics.

However, it should be emphasized that none of the problems mentioned in this section is really new. One might therefore wonder why most of the observers seem to have realized the costs that the patent system may place on innovation dynamics only very recently. Our explanation is that recent developments as regards the way the patent system is working make things worse. In particular, today too many patents are issued and patent information (including what exactly

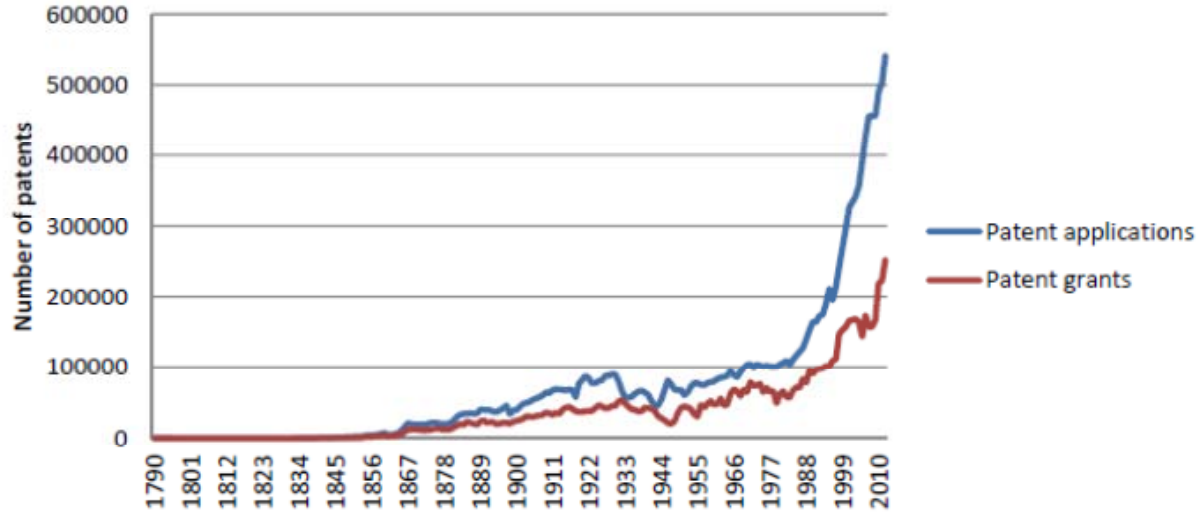
protects the patent) is often poor. And the combination of these two elements promotes inefficient strategic behaviors and complicates the lives of innovative companies.

4. How recent evolutions make things worse

4.1 The source of all evils: Proliferation of patents and poor patent information

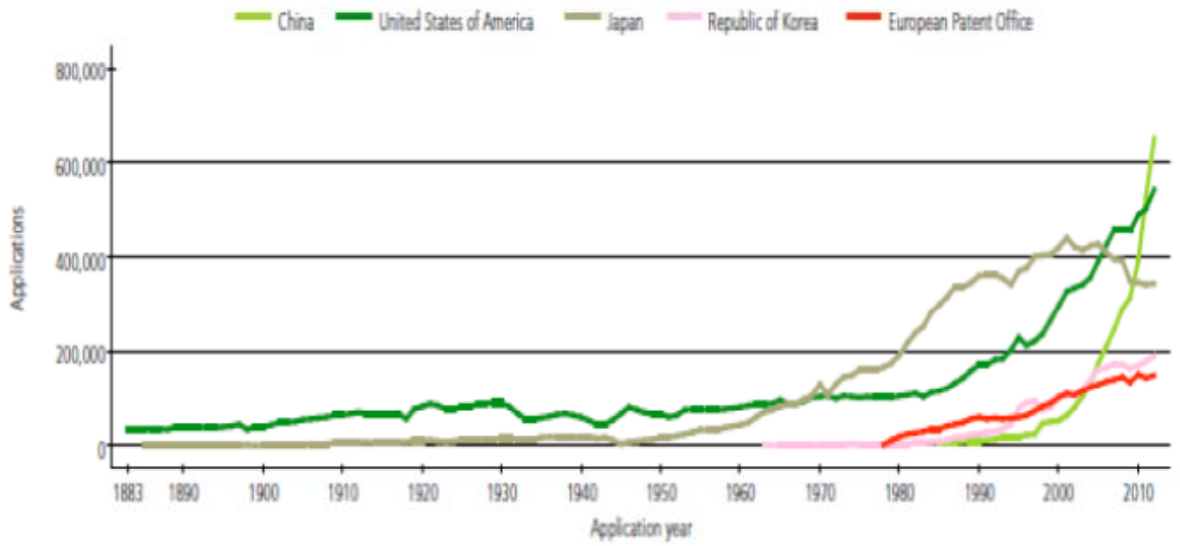
First, a huge number of patents are applied for and delivered every year in the world. For example, in the United States, in 2012, more than 500,000 patent applications were submitted to the USPTO which, at the same time, issued more than 250,000 patents (see Figures 1 and 2). Worldwide (so by adding national patents for the same invention), WIPO (World Intellectual Property Organization) estimates in its 2013 report that, for the first time, the mark of two million patent applications was passed in 2011, and that, in 2012, there were almost 2.5 million applications. At the same time, the number of patents granted in 2012 exceeded the million units to reach 1.2 million patents. As regard the number of patents in force, the same WIPO report estimated that there were in 2012 more than two million valid patents in the United States (2.24 million) and more than 8 million valid patents worldwide (8.66 million)[14].

Figure 1: Patent applications and grants at the USPTO (1790-2012) (source: USPTO 2013)



[14] See *WIPO Indicators 2013*. Figures are based on data collected in 82 patent offices worldwide. The USA remains the country with the highest number of patents in force (2.24 millions), followed by Japan (1.7 millions) and China (0.9 million). Germany (549 521) is fifth and France, sixth (490 941).

Figure 2: Patent applications in five major patent offices (1883-2012) (source: WIPO: 2013)



Is it reasonable that firms apply for and that patent offices grant so many patents? It should be recalled that a patent must be delivered only for inventions that are new, non-obvious (inventive step requirement) and have an industrial application (are useful in the United States). Can we believe that there are every year, worldwide, several hundreds of thousands of inventions that fulfill these requirements? Rather, we tend to believe that today a large number of patents include inventions not really new and with modest and marginal level of inventiveness, which helps feed the patent inflation worldwide.

Second, patent information is often poor and difficult to understand, thus preventing the realization of exhaustive freedom to operate analysis. Menell and Meurer (2013) talk about "notice failure" or "notice externality" to refer to informational problems related to patents. If poor patent information is naturally correlated with the proliferation of patents described above (more patents complicate the analysis of existing patents as individuals have limited cognitive processing capacity), it is also linked to three additional elements:

- Relevant patents (the ones that an invention is likely to infringe) are often difficult to identify. In the case of land property, the land registry allows an individual to be aware clearly, rapidly and in an unambiguous manner of who his/her neighbors are. Yet, the equivalent to the land registry does not exist in the case of patents (the International

Patent Classification – IPC - is of very limited use in order to define "adjacent inventions") and thus it is very difficult for a company to be sure when it infringes existing patents;

- The scope of patent protection is not always defined in an intelligible way. In particular, the manner patents are drafted contributes to blurring the information. Patent documents are often very long (sometimes more than 100 pages) and written in an abstract and vague style. In many cases it is hence difficult to understand, even for the expert, what is really covered by the patent and what is not;

- Patent stakeholders are not always clearly identifiable. Especially when licenses are granted, the information is not always made public. Also, it is difficult for firms to know who are the firms in charge of the management of some patents that could interfere with their technologies and therefore it is difficult to negotiate access rights.

In the end, it seems clear that patent information is not as clear as information on property rights for tangible things, such as land ownership for example (Bessen and Meurer, 2008). If it is easy to determine when someone intrudes on a private garden or steals a car, it is more difficult to agree on the fact that there is patent infringement or not. Menell and Meurer, for instance, explain:

> « *In modern real estate markets, notice rarely poses a serious problem for property development. Land boundaries are typically recorded in government administered and publicly accessible recording offices. Landowners can usually determine who their neighbors are, the boundaries of their land, and restrictions on land development relatively easily. This enables property owners to assess the parameters for developing their land and, when they wish to exceed those parameters, the counterparties with whom they need to bargain for additional rights […] Effective notice is a far greater challenge when the resources in question are intangible […]*
>
> *[To check patent] is not an easy task given the millions of issued patents (plots of intangible real estate). Unlike real estate maps, [patent] records are not organized geographically. The PTO's classification system was (and remains) outdated and does not deal well with cutting edge technologies for the simple reason that it is difficult to "map" intangible terra incognita. Furthermore, the proliferation of digital technology patents creates countless new neighbors, often with fuzzy, multidimensional boundaries* »
>
> (Menell et Meurer, 2013, p. 2)

4.2 Patent proliferation and bad information: Which consequences?

The combination of the large number of patents in force in the world with the poor quality of patents information has several severe adverse effects on innovation. In particular, it:

1) Promotes the fragmentation of intellectual property and increases the risk of anti-commons ("royalty stacking"). The tragedy of anti-commons is indeed induced by the combination of two factors: high transaction costs and the problem of multiple-marginalization (David, 2011). And the proliferation of patents and bad patent information increases both problems. If a product requires negotiating access rights with hundreds of patent holders (due to the multiplication of overlapping patents), the risk that the overall price is too high in the end is important. Also, transaction costs are growing when information is uncertain.

2) Increases the risk of "hold-up" and feeds "trolling". "Hold-up" is indeed directly related to the ability of companies to conceal their patents (Pénin, 2012). Also, the proliferation of patents and the difficulty of analyzing patent literature complicate the realization of freedom to operate analysis, thus favoring trolls' designs. In a world where millions of patents written so that their scope of validity is particularly difficult to interpret are in force, dissimulation is easy. And the more patents are granted and the poorer the information on these patents, the easier it is to provoke hold-up situations, thus reducing incentives for manufacturing companies to invest in R&D. Conversely, in a world where the number of patents is limited and patent information is clear and readable, it is difficult to provoke hold-up. Companies trapped in this situation are especially those who made mistakes in their freedom to operate study[15].

[15] Consequently, it is often considered that trolls' business model is legitimate since they only punish firms which have made mistake in their freedom to operate analysis (have missed some relevant patents) (McDonough, 2006). However, this argument holds only in a world where patent information is good. In such a world, a firm trapped in a situation of hold-up is indeed the only guilty. She made a mistake and will have to pay for it. But in a world where patent information is particularly difficult to understand this argument does not hold any more. Exhaustive freedom to operate analysis become too difficult to perform and the probability to make a mistake (miss a relevant patent) is very high even if a company devotes many resources to watch patent literature.

3) Increases transaction costs and reduces the efficiency of markets for technologies. A major interest of the patent system is that, since it contributes to solving the Arrow's paradox, it facilitates the functioning of markets for technologies and allows the emergence of companies specializing in the production of knowledge (see Section 2.2). In other words, patents help organize the sequential process of innovation (Scotchmer, 1991; 2004). Yet, Menell and Meurer (2013) argue that this vision is too optimistic ("too contract friendly"). In practice, the multiplication of patents and bad patent information can destroy the positive effect that patents have in theory on sequential innovation. Poor information is indeed a central cause of transaction costs. As mentioned in Section 2.2, intermediaries (technology and patent brokers) can help decrease those transaction costs. But, again, the presence of these actors looks like a bandage which is placed over a wound. Obviously, it would be preferable to prevent the formation of the wound.

4.3 Why so many patents? Why is patent information so bad?

The current situation is due to two complementary phenomena: On the one hand firms file a tremendous number of patents and, on the other hand, the quality of the patent examination process is often questionable, especially because examiners do not have the resources (mainly time) to conduct a comprehensive and in-depth review. These two phenomena are self-reinforcing. The more patents are filed, the more the review process is stretched, thus increasing the likelihood of congestion and thus encouraging examiners to reduce the average time spent on the examination of a given patent. And, conversely, when the examination process is not done in a proper way it becomes easier for firms to obtain patents even on dubious inventions, thus encouraging firms to file patents for strategic reasons and feeding patent inflation. It is therefore necessary to understand 1) why companies file so many patents; and 2) why so many patents are accepted despite a degree of novelty and inventiveness which is often questionable.

The increase in the number of patents in the world at the turn of the 1980s has many explanations. The emergence of new categories of applicants (public research organizations for instance), the development of new high-tech sectors in which firms are used to patenting extensively (life sciences, ICT), the globalization of the economy, each have contributed to increasing the number of patents worldwide (Kortum and Lerner, 1999). However, another

explanation may dominate, namely the fact that, increasingly, firms use patents strategically. Anticipating a rough examination and a high granting probability, firms are encouraged to file patents. Also, the delay in obtaining a patent can become a strategic argument for some companies, which speculate on the legal uncertainty that occurs during the time the patent is pending. The patent being filed but not yet granted, it creates uncertainty for competitors and can benefit the applicant. In order to scramble the information some firms also fragment their patent filings and apply for many patents on the same invention. Or they write long patents, so long that they become incomprehensible and difficult to analyze. Finally, given the moderate cost of filing a patent, some companies may even use patent offices as a way to outsource their technology watch.

This strategic use is often accompanied by poor understanding about the real economic issues around patents. The patent is regarded as sacred, seen as the ultimate weapon that firms must possess. Also, firms, the general public and business analysts often consider patents as indicators of innovative business success. Companies, then, file patents mechanically, without analyzing the disadvantages or the potential of alternative strategies. In particular, large groups' top management is often misinformed about the real issues and imposes pressure over its research departments, encouraging them to systematically apply for patents or, sometimes, fixing some quotas. Fixed budgets are allocated yearly to the management of patents, thus prompting actors in the field to exhaust these budgets and to apply for patents even in the absence of significant inventions.

Filing a patent becomes therefore a default choice for many firms which file patents automatically, often on marginal inventions with questionable novelty and inventive steps. In an ideal world, it would be the mission of patent offices to eliminate these patents, but, unfortunately, they rarely have the means to do so. The important number of patent applications induces congestions in the examination process and implies that patent examiners are overworked. This increases the time needed to obtain a patent. As a consequence, since patent offices do not want to unreasonably extend the examination period, patent examiners are subject to significant pressures to accelerate the review process. This often leads to incomplete

assessments and contributes to the granting of patents on inventions that do not necessarily deserve it.

Congestions in patent offices are due to the growing number of patents, but also to their growing sizes, that is to say the number of pages or the number of claims. On average, the length of patent application has been indeed steadily increasing. Today patents can sometimes be over 100 pages long. And obviously, the more patents are filed and the longer those patents, the heavier the workload for examiners, especially if their number does not increase. For instance, at the European Patent Office, applications were multiplied by 10 between the early 1980s and 2006. Similarly, the total number of pages was multiplied by 5.5 between 1990 and 2005. At the same time, the number of examiners was multiplied only by 2 (Guellec and van Pottelsbergue de la Potterie, 2007). Moreover, this increase in the number and length of patents is also accompanied by an evolution of the technology towards more complexity, which also increases the work of examiners.

In the end, in the same way that the choice to file patents is increasingly a default choice for firms, the decision to accept a patent is also more and more often a default decision for examiners. This means that to get a patent is becoming the norm whereas it should be the exception, thus contributing to the proliferation of patents of dubious quality. And, in the absence of new measures, the exploration of future trends suggests no improvement. Without significant changes (*ceteris paribus*) the management of the backlog (past patent applications) can only imply a reduction of the resources allocated to each application, with the risk of accepting bad patents, thus substituting quantity to quality (Guellec and van Pottelsbergue de la Potterie, 2007, p. 217).

5. How realistic patent reforms can solve most of these problems

Reforms mentioned by President Obama in the quote highlighted in introduction of this text should have two goals: To reduce the number of patents and, most of all, to improve patents information.

First, in order to reduce the number of patents it will be necessary to change the approach of the patent examination process and the philosophy of the stakeholders involved in it. Today, as explained in the previous section, in case of doubt, by default, patents tend to be accepted. However, it is important to remember that any patent granted to a firm penalizes the other firms. As Harhoff (2009) recalls, patent offices are the guardians of the temple. It should be made clear to patent examiners that it is as important to reject patents as to accept them. All the stakeholders should be conscious of the importance of rejecting patents for society. By default, in case of a doubt on the degree of novelty or the inventive activity for instance, it may be preferable to reject rather than to accept patents. This is a classic case of statistical type 1 versus type 2 error. Today, type 1 error (to refuse valid patents) is minimized at the cost of a high type 2 error (to accept invalid patents). It may thus be necessary to re-balance the process. Increasing the "technology gap" (the novelty and inventive step requirements in order to obtain a patent) could, for example, reduce significantly the number of patents in the economy.

In order to solve the issue of congestion at patent offices, it is also possible to increase the price of obtaining a patent (Harhoff and Hall, 2012; de Rassenfosse and van Pottelsbergue de la Potterie, 2012). For many observers, the unique role of patent fees is to finance patent office operations (de Rassenfosse and van Pottelsberghe de la Potterie, 2012). But for economists this role is secondary. The cost of obtaining a patent (which somehow amounts to the price to get a patent) is primarily an instrument of economic policy which allows applicants to change their behaviors (Eckert and Langinier, 2013). Standard economic theory predicts indeed that the demand for patents decreases with their costs. In addition, an increase in costs would likely reduce the strategic use of patent offices by applicants and limit low quality patent applications (for which expected revenues might be lower). De Rassenfosse and van Pottelsbergue de la Potterie (2012) and de Rassenfosse (2013) show that the cost of patenting affects applicants' behaviors. However, they also show that the price elasticity of patents demand is low, implying that only a significant increase in patent fees is likely to significantly reduce the number of requests (it should be noted however that it is possible that the elasticity is greater for lower quality patents) [16].

[16] One possible explanation of the low price elasticity of patent demand may be that the legal cost of application (what is paid to patent offices) is relatively low as compared to the total cost of patents for users (lawyer fees, advisors, translations, etc.

Patent application cost can also be modulated in a more sophisticated way, in particular by introducing price discrimination. For instance, the number of claims and/or the number of pages could be taxed (as it is already done in some patent offices), i.e. patents with more claims and/or more pages would be more expensive. This may reduce the length of patents and shorten the duration of patent examination. Cost discrimination may also contribute to preventing the filing of strategic patents that are never examined because the applicants withdraw their applications just before the examination (which may yet occur several years after filing. Such practices are called "pre-emptive patenting"). A remedy to fight against these strategies may be to increase fees that firms have to pay when they apply for a patent and then repay a share of those fees as soon as the patent is examined or even granted (Guellec *et al.*, 2012). To reduce the problems of congestion, Lemley and Lichtman (2007) also suggested offering applicants a menu of different possibilities: Firms could, for instance, opt for a less rigorous examination process, faster but with a lower presumption of validity; Or they could opt for an in-depth examination process, longer but with a stronger presumption of validity once the patent is granted. Yet, we suspect that such a menu might lead to an augmentation of patents with low presumption of validity, thus still increasing the legal uncertainty and leading to a business climate not favorable to innovation and investments. Finally, Caillaud and Duchêne (2011) show that the introduction of a penalty to the applicant in case his application is refused would be a powerful tool to reduce the number of poor quality patents and increase economic efficiency. Refinements on the role of patent application cost are numerous and deserve to be discussed seriously. In particular, opening such a discussion has at least the merit of offering a counter-argument to many users of the patent system (firms, lawyers, translators) who regularly point out that the cost of obtaining a patent is too high and should be significantly reduced.

Concerning the improvement of the quality of patents information, several elements of reform can be envisaged. Menell and Meurer (2013) stress six lines of changes[17]. We limit ourselves to two fundamental points:

[17] "*(i) a publicly accessible registration system; (ii) full, clear disclosure by claimants; (iii) reliable and prompt examination of resource claims; (iv) transparent notice information and registry search tools; (v) clear and efficient marking of claimed resources; and (vi) institutions for resolving boundary disputes, preferably before significant investments have been made*" (Menell and Meurer, 2013, p. 30).

Above all, boundaries of the patent space must be redefined in order to enable firms to reliably identify their "patent neighbors". In other words, we need for patents the equivalent of the public land registry for land ownership. This requires, among others, to rethink patent classifications. The latter should aim at allowing firms to clearly identify whether or not they have the freedom to operate, i.e. whether or not they infringe other patents. For example, patents that are not located in the same sub-unit of the patent classification of a given product should not be able to block the production and marketing of this product. A coherent patent classification would help firms identify their neighbors in order to avoid infringing them or in order to negotiate access rights with them. In the same vein, it is essential that patent holders can be identified without ambiguity. Today in most countries patent reassignments (when a firm buys a patent from another firm) are made public but licensing agreements are not. This introduces uncertainties about who the real stakeholders are. A public database including also licensing agreements should allow firms to clearly identify each stakeholder (owners, licensees, etc.). This would imply requiring companies to also publicly declare their licensing agreements.

In addition to these measures, it is essential to fight against any form of secrecy, attempt to conceal and dissimulate information and/or to blur patent information. Today, patent applications can remain secret during 18 months after the priority application. There is little economic rationale to this favor made to patent applicants. Why, then, do patent offices not require firms to publish their patent applications as soon as the application is filed? Also, firms have at their disposal several means to extend the duration of the examination process. This introduces legal uncertainty for other companies. As mentioned above, discriminating on the costs of obtaining patents could largely correct these effects. Furthermore, it is essential to encourage firms to write patents whose boundaries are clear and easy to understand. Hence, examiners may well reject systematically any application considered as ambiguous. Penalties on companies that conceal or blur information could also be introduced (Menell and Meurer, 2013). Finally, the examination process could be open to third parties, including competitors, in order to provide more information on the degree of novelty of inventions (this solution has been tested in the United States for instance).

6. Conclusion

This paper aimed at providing an update on the most recent patent economic literature. We showed that, contrary to the standard view that emphasizes only static costs, patents may negatively impact the dynamics of innovation by increasing transaction costs and generating situations of anti-commons and "hold-up". However, these problems are not intrinsic to the patent system. They come mostly from some recent misuses that imply that, today, too many patents are granted and patent information is bad. Hence, realistic reforms could address these two problems and significantly improve the situation by reducing the number of patents in force and improving patent information. This could be done, among others, by modifying applicants' and examiners' behaviors but also by changing patent stakeholders' philosophy. It is important that any person involved in patenting activity realizes that the present situation cannot last very long.

The core message in this article is primarily a warning message. Several decades ago, Machlup (1958), commissioned by the Senate of the United States to audit the U.S. patent system, concluded that given the current state of knowledge, and despite the problems identified, it would be irresponsible to recommend to abolish the patent system[18]. However, at the rate things are moving, the risk is that the dysfunctions related to patents become so unbearable that, under pressure from a growing number of opponents, the patent system may simply be abolished. To avoid reaching such an extreme end it seems important to launch patent reforms today. To use Schumpeter's analogy with car brakes set at the beginning of this article, if we aim at avoiding severe accidents in the future, we must repair the brakes now. It is certain that some reforms will penalize innovative companies[19]. But, as always with patents, the objective may not be to reach a first best but, more modestly, to reach a fair balance between the interests of all stakeholders.

[18] "*If we did not have a patent system, it would be irresponsible, on the basis of our present knowledge of its economic consequences, to recommend instituting one. But since we have had a patent system for a long time, it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it*" (Machlup, 1958, p. 80)

[19] For instance, in the fight against patent trolls, Pénin (2012) shows that most of the policy reforms that would deter trolling are also likely to harm technological firms. He concludes therefore that there exists a positive optimal level of trolling that must be tolerated in the economy.

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