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1 INTRODUCTION

Patents are a type of Intellectual Property Rights (IPRs), which provides a period of exclusivity, a temporary monopoly, for the exploitation of a technical invention (Levin, Klevorick, Nelson and Winter, 1987). Thus, patent-holders acquire, for a limited period of time (typically 20 years from the filing date), the rights to prevent others from using, commercializing or importing the patented products or processes. As a trade-off, innovators have to disclose important information about their inventions; they have to describe the possible uses of their inventions and the information they disclose has to be detailed enough to allow an expert in the relevant technological field to replicate the invention. After the expiration of the patent, anyone can use the initially protected knowledge for commercial purposes.

The underlying logic for a patent system is quite simple: the temporary monopoly right provides incentives for inventors to engage in costly and risky research and development activities, while the obligation to disclose information about the invention makes it possible for other inventors to access the knowledge freely, but not necessarily free of charge. Thus, the patent system should be able to stimulate innovation and its subsequent diffusion, and the diffusion of innovation is one of the main engines of economic growth (Romer, 1990).

Over the last decades, and especially during the beginning of the 21st century, the nature of the innovation process has changed dramatically. The complexity of the technology landscape makes each new invention highly dependent on a myriad of pre-existing and parallel technological developments. As a consequence, institutions such as the patent system, which was put in place centuries ago with the aim to promote collaborative innovation as opposed to the then-predominant secret know-how based closed innovation, have proven to present some imperfections to adequately manage innovation in the current scenario, especially in the information and communication technologies (ICT) sector. Technological products such as smartphones or laptops require licenses of hundreds or even thousands of patents, and in many cases, the exact application area of these patents are fuzzy (Biddle, White and Woods, 2010). This creates a complex interdependency scenario in which exclusion rights involving a scarce resource, such as those arising from patents, hinders the availability of technology (Heller, 1998). In fact, patents become powerful tools to stop the implementation of the technology instead of promoting it. This has brought in an escalation in the filings and the legal costs of patent enforcement, often associated with 'Patent Wars'.

The difficulties associated with the Patent System have prompted several responses by the government, industry associations and individual companies. Patent pools, cross-licensing, compulsory licensing, patent pledges, patent purchase programs have flourished together with the rise of new players, like for instance patent aggregators, patent assertion entities, patent clearinghouses, and patent trolls. Some of these solutions have proven solid, others are debatable.

The aim of this paper is to provide a structured review of the main virtues and drawbacks of the Patent System, with a specific focus on its societal impact and the idiosyncrasies of the

ICT sector. In addition, the paper presents and assesses the main solutions emerged in recent years in response to the problems caused by the fragmentation of patent rights, which is particularly salient in ICT. Overall, it contributes to a better understanding of the issues at stake and helps set the ground for advancing workable proposals to improve the current status quo.

2 Virtues of Patenting

2.1 Incentives to innovate and protection of IPR

Patents help inventors secure a return on their efforts to come up with and create an invention. Without it, inventors and companies could easily be deprived of the returns they deserve for having invested efforts and resources, especially if the technology could be reverse engineered (Gallini, 2002).

Prima facie, thus, the patent system is a well-functioning mechanism to incentivize inventors to create new knowledge and companies to invest in R&D: patents guarantee, through the temporary monopoly power perspective, that upfront costs of inventions will meet earnings from commercialization of a product exploiting that invention. Furthermore, as we will mention later, holding the right on an invention gives also the possibility to license it in exchange for a monetary compensation, which is a second appealing way to monetize inventive efforts.[1]

Patent applications increased steadily during the last decades. A study by WIPO (2014) provides an estimated number of more than 2.5 million applications filed world-wide in 2013, up 9% from the previous year. Only in the U.S., total patent applications increased from just above 0.1 million a year in 1980 to more than 0.6 million a year in 2014 (Schilling, 2015).[2] The EPO's 2015 annual report shows a new high in the number of European patent filings at nearly 279000 (about 160000 filed at the EPO).

However, it is unclear that this upsurge in patent applications reflects an underlying increase in innovation activity. The total number of patents is the outcome of the potential pool of innovations that can be patented and the patent propensity (Arora, Ceccagnoli and Cohen, 2008). If the increment of the number of patent applications is mostly due to a change in patent propensity, then the benefits in terms of increased incentives to innovate do not materialize.

Interestingly enough, the empirical evidence on the role of patent protection on the incentives to innovate remains debatable. Empirical studies based on survey evidence

[1] However, it is not at all clear that patents, or stronger patents, do always increase the incentives to engage in innovation activities. Stronger patents mean that both a focal firm's patents and the patents of its rivals are more enforceable (Jaffe, 2000; Gallini, 2002). Thus, knowledge spillovers are reduced, and if internal R&D investment is complementary to knowledge spillovers, firms might reduce their inventive effort. As we will discuss later, where technologies progress cumulatively and patents are broad, the profit maximizing licensing decisions of upstream inventors may retard downstream innovation (Scotchmer, 1991).

indicate that firms in most industries do not feature patents among their various means of protection (Cohen, Nelson, and Walsh, 2000); however, research on patent renewals suggest—at least for Europe—that patent protection does yield a return, sometimes substantial (e.g. Deng, 2007). In a meta-analysis, conducted by Boldrin and Levine (2008), of 24 studies published up until 2006, the authors conclude that: *"these studies find weak or no evidence that strengthening patent regimes increases innovation; they find evidence that strengthening the patent regime increases patenting! They also find evidence that, in countries with initially weak IP [intellectual property] regimes, strengthening IP increases the flow of foreign investment in sectors where patents are frequently used."* In a more recent paper, Boldrin and Levine (2013) refer to this as the "patent puzzle": in spite of the enormous increase in the number of patents and in the strength of their legal protection, we have neither seen a dramatic acceleration in the rate of technological progress nor a major increase in the levels of R&D expenditure.

However, other authors find systematic evidence that stronger patent protection leads to more patents and additional R&D investment. Arora, Ceccagnoli and Cohen (2008), using survey data for the U.S. manufacturing sector, estimate the increment to the value of an innovation realized by patenting it, and then analyze the effect of changing that premium on R&D. They show that patent protection also stimulates R&D across all manufacturing industries, although the magnitude of that effect varies substantially.

Patents are particularly helpful to secure the returns on inventive efforts to small companies because they usually lack other means to protect their innovation and have limited access to complementary assets (Teece, 1986). There is empirical evidence showing that patents can facilitate funding for startups or small companies with little resources. For instance, Farre-Mensa, Hegde, and Ljungqvist (2016) show that the approval of a startup's first patent application increases its likelihood of raising venture capital (VC) funding in the following three years by 3.5 percentage points—a 59% increase relative to the unconditional probability of raising VC funding. They conclude that "*patents are particularly beneficial to early-stage startups, those founded by inexperienced entrepreneurs, those located in states with a large startup population, and those operating in the IT sector*". Technology startups with secured patent protection can simply enter the market as upstream specialists, with a business model based on licensing instead of manufacturing (Arora, Fosfuri, and Gambardella, 2001). *"Patents can therefore be viewed as increasing entry and competition by lowering the cost of market entry for upstream specialists"* (Geradin, Layne-Farrar, and Padilla, 2012). A (positive) side effect of this division of inventive labor is that it could *"also encourage the entry of downstream specialists that would otherwise not enter if doing so required the development of in-house technology."*

In short, an important channel through which patents might affect innovation outcomes is by changing the market structure. Upstream entry favors downstream entry and a more competitive environment spurs improvements in productivity. This is referred to as vertical disintegration and specialization, and we can expect greater entry whenever specialization is possible (Geradin et al., 2012). So, to the extent that patents favor the vertical division of inventive labor (Arora and Gambardella, 1994), there are increased incentives to innovation activity and gains in productivity.

2.2 Diffusion of information: codification of knowledge

As mentioned before, when applying for patent protection the inventor accepts the main condition required by this system, that is, the codification of the knowledge embedded inside the invention into a document, the patent, with its claims and detailed description, and its subsequent publication. It is in fact accessible by anyone to be seen and studied, through for example, a large amount of databases[3]. Not only that, but the invention itself belongs to the public once the patent expires, thereby allowing anyone to use it: this is especially important, for example, in the pharmaceutical industry, in which generic drugs can be developed out of expired patents (Caves et al., 1991). This fact is probably the aspect in the patent system with a greater positive impact on societal progress and welfare. As an example on the different societal impact of patented technology as opposed to non-patented technology, which is kept secret, we have the case of the saxophone and the violin manufacturing processes. The saxophone was patented in 1846 in France by Adolphe Sax, with 14 further patents by him and competitors following in the next 70 years. As a result, the technology to build a saxophone is now in the public domain and anyone can make or use the saxophone. On the contrary technics to make violins in Italy during the 17th and 18th centuries were family secrets passed from generation to generation. As a result, nobody can nowadays make a violin following the process used by Stradivarius (Gurry, 2013).

Another important effect for the diffusion of knowledge is the incentives that the Patent System generates for the codification and organization of new knowledge in ways that are meaningful and useful to others. This is particularly important when innovation systematically originates in firms that will not develop and utilize the knowledge themselves (Arora and Gambardella, 1994). Unfortunately, systematic empirical evidence for this impact is difficult to find. A recent paper by De Rassenfosse et al. (2016) finds mixed evidence.

In practice, the standardized terminology used in patents is recognized by members of the patent drafting community as having an established meaning, which means that it can constitute a common code for purposes of licensing or similar negotiations (Burk, 2008). Because of regulatory requirements, as well as common practice, the format of a patent is relatively uniform. In licensing negotiations, documents with a standardized presentation, common jargon and layout are used, which entails substantial savings in examination or interpretation of the patents. That is why the licensor is likely to be advised by a patent attorney or agent familiar with the "code" used in patent documents (Burk, 2008).

2.3 Help to sustain technology transactions

Patents are supposed to encourage the development of technology markets by making easier, more fluent and organized the exchange of knowledge. As referred in Cockburn et

[3] Guide to technology databases by the World Intellectual Property Organization: http://www.wipo.int/edocs/pubdocs/en/patents/434/wipo_pub_l434_11.pdf

al., (2010) *"patents and other forms of intellectual property are a critical 'infrastructure' for markets for technology."* First, the direct cost of knowledge transfer is lower when the knowledge is codified and systematically organized (Arora and Gambardella, 1994). Second, technology transfer requires substantial amounts of know-how, which is costly to transfer. The transfer costs are high in part because contracts for know-how are inefficient. However, patents can help improve the efficiency of licensing contracts (Arora, 1996). Some recent papers have explored these effects empirically. For instance, Gans, Hsu and Stern (2008) show that licensing deals occur earlier when patent rights are more clearly defined. Indeed, they show that there is a bulk in the probability to license a patent around grant date. Along the same line, Hegde and Luo (2017) argue that mechanisms that make information about technology publicly available reduce the time to license of patented technology.

A third potential contribution of patents to encouraging technology transfer is indirect. By facilitating transactions in technology, patents allow both small and large innovating firms to increase economic value gained from innovation. For the former, patents facilitate the licensing and the selling of technology to firms that have the downstream capabilities (Arora and Merges, 2004). For the latter, patents help leveraging economic value from intellectual assets, accessing and exchanging technologies (Arora, Fosfuri, and Gambardella, 2001). In other words, patents facilitate the vertical specialization of companies in innovation activities (Geradin et al., 2012). The best example is the transfer of technology between biotechnology firms and big pharmaceutical firms.

3 Drawbacks

3.1 Monopoly power

While the implementation of a patent system affords many benefits in terms of increased incentives for the development of innovation, codification and diffusion of knowledge, and ease of commercialization of innovations, the first and most important drawback is that patents attribute to their holders a monopoly on the use of the technology for which they are issued. Monopolies are problematic because standard neoclassical economic analysis (e.g. Bergson, 1973; Tullock, 1967) shows that the contribution of a sector to the overall level of welfare of a society is maximized in a situation of perfect competition and minimized in a monopoly.

Nevertheless, the current set up of most patent systems around the world is rooted in a vision of knowledge that goes back to the seminal work of Schumpeter (1934), Nelson (1959), and Arrow (1962). According to this view patents are a necessary evil. Knowledge in fact is regarded as a non-rival and non-appropriable good and, as such, it is highly subject to spillovers. Valuable knowledge flows from individuals and firms producing it to other agents that enjoy the benefits without sustain the cost of its production. The presence of these negative externalities implies that overall the agents operating in an economy will produce a total amount of knowledge that is less than optimal (Coase, 1960). Patents in theory solve this problem by granting the exclusive legal right to exploit an innovation. Therefore, the adoption of patents can be viewed as an attempt to find an optimum between the benefits for society of increased incentives for innovation, and costs for society of granting temporary monopolies.[4]

However, where technologies progress cumulatively and patents are broad, the deadweight loss associated to the temporary monopoly power is likely to be larger (Scotchmer, 1991). Later innovators might experience reduced incentives because the patent holders on early innovations engage in sub-optimal behaviors. As we discuss below this problem is particularly salient when patent landscapes are fragmented.

Finally, in some industries, such as ICT, the duration of a patent makes little sense given the pace of technological progress. Thus, firms are granted with a long period of monopoly power over products that have much shorter lifecycles. Bilir (2014) shows that multinational investment is sensible to stronger patent protection in those sectors in which products have a long lifecycle; however, he finds no effect in those sectors with short product lifecycles.

3.2 Fragmentation of IPRs

3.2.1 Patent thickets

Shapiro (2001) defines patent thickets as *"a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology"*. Patent thickets arise when different patent owners hold complementary patents. This kind of situation is problematic because it can create the conditions for which companies may block each other's use of the technology protected by the intricate set of patent claims. The more complex the technology, the higher the likelihood that the company will experience patent thickets (Von Graevenitz, Wagner, and Harhoff, 2011). A technology is considered complex if new commercializable products or processes based on it are comprised of numerous, separately patentable elements versus relatively few ones (Cohen, Nelson, and Walsh, 2000). It can be noted that this is the case of most technologies in the ICT sector, for instance cellular networks technologies.

Patent thickets are associated with increased transaction costs for companies. For example, Ziedonis (2004) finds that firms operating in a fragmented market for technology tend to patent more aggressively in order to avoid rent expropriation by other parties. This tendency is reinforced by the presence of large investments in technology-specific assets coupled with a strong appropriability regime. Likewise, Cockburn & MacGarvie (2011) show that the presence of patent thickets (as proxied by patent density in a market) is negatively associated with the choice of entry to a given product market. A recent study of the impact of patent thickets in the UK (Hall, Helmers and von Graevenitz, 2017) shows that they raise entry costs, which leads to less entry into technologies regardless of a firm's size.

As we will discuss in depth later, the literature has focused on a variety of cooperation mechanisms that might provide some relief from the IPR fragmentation problem, such as: patent pooling (Bittlingmayer, 1988; Joshi and Nerkar, 2011; Merges, 1996), standard

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[4] However, Boldrin et al. (2011) conduct a large sample statistical analysis and find no evidence of a correlation between measures of productivity (both labor and total factor productivity) and measures of patenting activity (patents granted and citations).

setting organizations (SSOs) (Shapiro 2001) and consortia (Baron and Pohlmann, 2013), cross-licensing (Grindley and Teece, 1997), and even tacit patent litigation “truces” between firms (Hippel, 1988). Accordingly, the evidence shows that these mechanisms help in reducing the problem of defensive patenting (Cockburn, MacGarvie, and Müller, 2010). Nevertheless, these solutions are limited in their ability to solve the issue. In the presence of excessive fragmentation, coupled with high asymmetry of information about the value of technology, it is likely that the holders of complementary patents will not be able to agree on the terms.

3.2.2 Patent wars

Paik and Zhu (2016) defines patent wars as *“battles among multiple firms to litigate regarding patent rights, or to secure patents for litigation, whether offensively or defensively, and other closely related events (e.g. patent portfolio acquisition)”*. Patent wars are likely to erupt when cooperation mechanisms, such as the above-mentioned pooling and cross-licensing, become non-sustainable. An example of such situation can be the case in which a portion of the patent thicket characterizing a technology becomes crucial in establishing a technological standard or a dominant platform in a growing industry (Simcoe, Graham, and Feldman, 2009).

In general, patent wars are likely to erupt whenever the expected payoff from offensive actions aimed at dominating the technological field exceeds the expected payoff from cooperation with other industry players (Somaya, 2003). Such behaviors are mostly witnessed in industries built around platforms or standards (e.g. the smartphone industry), where one or few major players quickly become dominant (Shapiro and Varian, 1999; Zhu and Iansiti, 2012). In industries presenting such high strategic stakes, cooperation mechanisms are likely to break down in the early stages of industry development (Lanjouw and Lerner, 2001) and patent owners are more likely to aggressively defend their patent rights against competitors.

3.2.3 Block innovation

The fragmentation of Intellectual Property Rights (IPR) that characterizes certain technological areas such as software, biotechnology and telecommunication is especially problematic because of its detrimental effects on the incentives for developing innovations (hold-up problems). The evidence supporting this claim is abundant. In a survey conducted with Swiss Biotechnology firms for example, Thumm (2005) finds evidence that the presence of blocking patents at times impedes the development of medical tests. Likewise Arundel and Patel (2003) report that 16% of the firms included in their study declared that they had to abandon research projects because of patents held by competitors. Based on a large-scale survey conducted with inventors in USA, Europe and Japan, Torrisi et al. (2016) report that about 40% of patents remained unused by their owners, and about 67% of patent applications were filed to block other patents. Also, Cho et al. (2003) report that the increased use of patents has resulted in less information sharing among researchers.

Even when fragmentation does not oblige companies to abandon R&D projects, it frequently forces them to engage in some sort of copying mechanism, such as taking legal actions to limit the IP held by others or acquiring additional IP rights (Mueller, Cockburn, and Macgarvie, 2013). One pending empirical question is related to the latter copying mechanism: To what extent can these hold-up problems be solved through licensing and collaborative agreements? The existing evidence regarding this question is limited and at times contradicting. A stream of the literature in fact argues that problems such as royalty stacking can be efficiently solved through multi-party negotiations (Galasso and Schankerman, 2010; Geradin, Layne-Farrar, and Padilla, 2007). Nevertheless, Siebert and von Graevenitz (2006) find a negative association between licensing and fragmentation. This relationship suggests that contracting might be possible only when the fragmentation of IPR rights is not too severe.

Finally, on the normative side, some scholars have investigated which factors are related to the optimal level of IP fragmentation from the point of view of the society. To this regard Kultti and Takalo (2008) demonstrate through a formal model how the optimal level of fragmentation is inversely related to the cost of developing innovation and to the rate of obsolescence of a technology.

3.3 Litigation costs: lack of freedom to operate

Patent litigation is a topic of extreme relevance for scholars, industry players and policy makers. According to a PWC report (2016), the total number of patent litigations in the US has been growing since 1991 at a 6.7% Compounded Annual Growth Rate to a total of more than 5600 cases in 2015. The growth rate is higher than the corresponding growth rate in patents granted, which over the same time-span has been equal to 4.9%. Not surprisingly, this trend has produced an increase in the amount of time it takes to judicial courts to process patent cases. According to the same report the median time-to-trial for the period 1996-2000 was less than a year, while the figure for the 2011-2015 period is more than two and a half years.

This increase in patent litigations is problematic for a number of reasons. First, patent litigations represent a heavy financial burden for firms and do not create any value for the society. Bessen and Meurer (2008) estimated that on average firms spend in patent litigation an amount equal to 14% of their total budget for research and development. Moreover, to prevent potentially destructive legal lawsuits, firms are at times forced to take drastic and costly actions. For example, the recent multi-billion dollar acquisition of Motorola by Google was mainly conducted to avoid lawsuits from Apple and Microsoft. The value of Motorola for Google in fact stemmed from the possibility of using the patent portfolio of Motorola to sue back Apple and Microsoft in case this would have been necessary (Boldrin and Levine, 2013). The use of patents mainly as a defensive mechanism is not something new as the same message emerged already decades ago from surveys conducted with R&D managers in the US (Cohen *et al.*, 2000; Levin, Klevorick, and Nelson, 1987) and partly replicated by Arundel and Patel (2003) for Europe and by Blind et al. (2006) for Germany. Recent years have also seen a surge in the number of lawsuits brought by Non-Practicing Entities, firms whose business model is focused on enforcing patents against infringers in order to receive settle payments (Golden, 2007; Lemley *et al.*, 2006, Pohlmann and Opitz 2013). The total number of lawsuits from NPEs went from 144 in 2001 to 3,134 in 2013 involving 3,716 producing companies (Fosfuri, Helmers, and Wehrheim, 2014). Software and telecom patents are generally affected by this problems more than patents in other technology fields (Allison, Lemley, and Walker, 2011).

A second reason for the problematic nature of patent litigation is that patent litigations are widely considered responsible for stifling innovation. Litigations are negatively related to the overall amount of within industry knowledge spillovers (Agarwal, Ganco, and Ziedonis, 2009). Therefore, litigations reduce the extent to which technological innovation becomes diffused and contributes to the overall welfare level of a society. A recent paper by Mezzanotti (2016) shows that patent litigation reduces investment in innovation by lowering the returns from R&D and by exacerbating financing constraints. Furthermore, litigations normally occur in mature industries when the elasticity of demand is high (Jovanovic and MacDonald, 1994). In such industries, established industry players have a stronger incentive to block innovation from competitors by enforcing their patent rights (Boldrin and Levine, 2004). As a result patent litigations often involve dying firms that have lost their ability to innovate and that try to stay alive by suing innovative industry newcomers (Boldrin and Levine, 2013)

Finally, litigations also negatively affect the functioning of the labor market for skilled knowledge workers. Ganco and Ziedonis (2015) for example show that patent litigations negatively affect the mobility of inventors across firms.

3.4 Disadvantages for small firms

The effect of the patent system on small firms deserves a few special considerations. To this regard, one side of the literature has argued that, for smaller firms, patents are an especially useful means of protecting innovation. For example, Arundel (2001) finds that a firm's preference for patents as a protection mechanism vis-à-vis secrecy is negatively related to the firm's size. The author attributes the finding to the fact that smaller firms are generally more likely to lack the complementary capabilities that are necessary to market innovations. This in turn makes this group of firms more likely to enter into partnerships with established industry players. As mentioned above Farre-Mensa et al. (2016) show that patents are particularly beneficial to early-stage startups and those founded by inexperienced entrepreneurs.

On the other hand, however, the empirical evidence shows that part of the problems of the patent system examined up to this point are exacerbated in the case of small firms. Small firms have a significantly higher litigation risk than firms with larger patent portfolios (Lanjouw and Schankerman, 2004). This latter group of firms in fact is more likely to find a cooperative resolution for a patent dispute. Schliessler (2015) finds that small and unexperienced defendants are more negatively affected by patent litigation than other firms, which the author attributes to the lack of ability to cope with financial distress. Small firms also have a harder time engaging in defensive patenting. Lerner (1995) reports that in a survey of biotech firms, 55 percent of small firms and 33 percent of large firms claim that litigation is a deterrent to innovation. Moreover, small firms are disadvantaged by the cost of preliminary injunctions: Firms requesting injunctions tend to be twice as large as those that do not and are significantly larger than the defendant (Lanjouw and Lerner, 2001).

Small firms are also more likely to suffer from the adverse consequences of patent thickets. Firms with smaller patent portfolios are in fact less likely to enter into product markets with high patent density (Cockburn and MacGarvie, 2011).

Finally, small firms and specifically startups suffer from long prosecution times. According to Farre-Mensa et al. (2016) each year delay in reviewing a firm's first patent application that is eventually approved reduces the firm's employment and sales growth over the five years following approval by 21 and 28 percentage points, respectively.

3.5 High (legal) uncertainties regarding determining prior art and granting

For a number of years most of the literature in economics has typically regarded patents as well-defined property rights that give their holders a competitive advantage in some markets due to the control over a more efficient method of production or over a particular product improvement (e.g. Nordhaus, 1969; Reinganum, 1989).

More recently however, economic and legal scholars have begun to look closely at the empirical evidence regarding the issuance of patents and patent litigation. Each year the USPTO grants more than 300000 patents, many of which are of dubious validity as testified by the fact that nearly half of the patent litigations result into a patent being declared invalid (see Table 1 below about grant rates in recent years). The observation of these trends has spurred some economists to reconsider their view of patenting in a probabilistic sense (Lemley and Shapiro, 2005; Shapiro, 2003). According to this view patents do not confer to their holders the right to exclude others from the unauthorized use of the innovation, but rather a right to *try* to exclude by asserting the patent in court.

Part of the reasons behind this increase in uncertainty can be traced back to the process through which patents are granted. The PTO for example requires the patent applicants to disclose the relevant prior art of which he/she is aware of, but not to conduct an exhaustive search of all the prior patents that are related to the invention. As a result, the PTO is frequently criticized for missing relevant prior art and thus improperly issuing patents (e.g. Lemley, 2001).

As patent proliferation has become an issue over the last years, Patent Offices around the world have been focusing on quality. As way of example, the so-called EPO "Raising the bar on patent quality" programme (EPO annual report, 2007) aimed at achieving better patent applications from the onset. Some proliferation trends impinging on the number of claims and an ever increasing number of obscure invention embodiments and description length have partially been reversed over the last years.[5] In addition, without prejudice to the patent applicants' obligation to disclose known prior art documents, Patent Offices have embarked on crowdsourcing efforts for finding all relevant prior art during patent examination. For instance, the peer-review pilot projects (peer-to-patent), has also attempted to create a community to support patent Examiners in finding the closest prior (http://www.peertopatent.org/).

[5] https://www.epo.org/about-us/annual-reports-statistics/annual-report/2007/focus.html

Furthermore, the problem of high legal uncertainty is complicated by three tendencies. The first is the expansion of the patentable subject matters over time (Gallini, 2002) . In the United States for instance, the Federal Circuit Court of Appeals included software to the list of patentable inventions in the 1980s and 1990s, and business methods in 1998. The second is the relaxation of the principle that an invention must be non-obvious and contribute non-trivially to prior knowledge in order to be granted a patent (Merges, 1992). For some technology areas this principle has been relaxed to a point where a large number of patents of dubious validity has been granted (Barton, 2003; Jaffe, 2000) thus increasing the chance that a given invention will infringe one or more existing patents leading to litigation. The third is a general propensity of inventors to file patent applications in areas of technology that historically have not been patentable (Lerner, 2002). This is due to a problem of incentives. In fact, the inventor that choses to keep his innovation secret could lose his rights over the invention to a second inventor who did choose to file for patent protection (Lemley and Tangri, 2003). As a consequence of this, inventors frequently file patent applications even in areas that are not currently eligible for patent protection, simply to hedge their bets (Lerner, 2002).

A mention is deserved to the phenomenon of submarine patents. Submarine patents are patents that are granted only after lengthy processes of unpublished applications (Gallini, 2002), which at times are intentionally delayed by the applicant (see also Berger et al. 2012 for standard-essential patents). These patents represent a great source of uncertainty for firms and are particularly problematic if they are used to sue companies that unintentionally designed infringing products before a submarine patent became public (Jaffe, 2000; Shapiro, 2000). During the last decade, Patent Offices have by and large adopted compulsory publication requirements for all kinds of patent-like protection. In appearance, this has mitigated the perils of unpublished submarine patents suddenly emerging as enforceable rights against unsuspecting technology implementers and commercial companies alike. However, the phenomenon has seen its sequel in the extensive use of divisional applications and continuations. These applications benefit from early priority dates that can effectively target alleged infringing products, long after these products have been introduced in the market. Many advocated that patents should not be allowed to be drafted ex post. To that end, the EPO unsuccessfully attempted to limit the time that divisional could be filed. So, the practice of allowing products to flood the market, target the future patent to the already known product has not been limited yet.[6]

4 Empirical trends on patenting

4.1 Number of patents in:

4.1.1 US

Starting from the middle of 1980s, patent applications and grants in the US have seen a sharp increase, as can be seen in Figure I below. However, based on surveys carried out in 1994 with R&D laboratories of about 1500 firms in manufacturing industries, Cohen et al.

[6] https://www.epo.org/news-issues/news/2013/20131018.html

(2000) report that companies rely most heavily on secrecy and lead times, and to a much lesser extent on patenting, with no change in the tendency to patent innovations. By focusing in the semiconductor industry, Hall and Ziedonis (2001) observe a sharp increase in patenting activity that they interpret as the effect of the emergence of a pro-patent court system during the 1980s in the US. However, Kortum and Lerner (1999) puts forward evidence to contrast the pro-patent court hypothesis. Instead, they find that a large chunk of the increase in patents was due to: a) the patentability of new subject matters; b) changes in patenting propensity by firms.

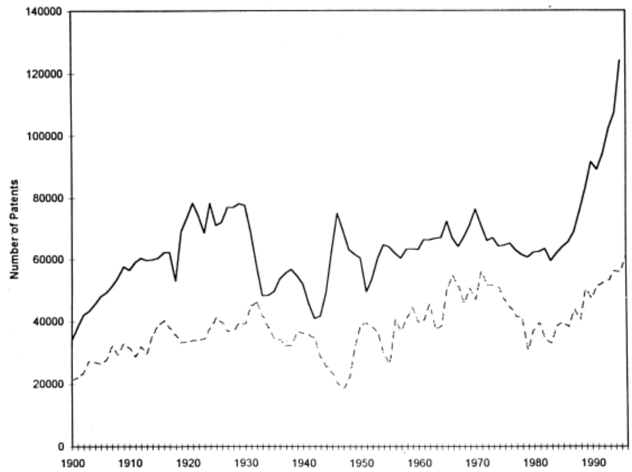

Figure I. Patent Applications (line) and Grants (dashed line) in the US between 1900 to late 1990s (from Kortum and Lerner, 1999, p. 2)

More recent years have seen increasing numbers of patent applications in the US with US-based inventors and foreign inventors applying for 288,335 patents and 301,075 patents in the U.S., respectively[7]. As it can be seen from Table I, recent years exhibit an almost monotonically increasing trend in the number of patent applications, although patent grants have been fluctuating more.

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Applications	425967	456154	456321	456106	490226	503582	542815	571612	578802	589410
Grants	173772	157282	157772	167349	219614	224505	253155	277835	300678	298407
Grant Rate	0.408	0.345	0.346	0.367	0.448	0.446	0.466	0.486	0.519	0.506
Foreign Apps	0.479	0.471	0.492	0.507	0.506	0.508	0.505	0.496	0.507	0.511
Foreign Grant	0.483	0.494	0.509	0.508	0.509	0.516	0.522	0.519	0.519	0.528

Table I. Number of utility patent applications and grants in the U.S over the recent years

[7] U.S. Patent Statistics for 1963-2015 period: https://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm

4.1.2 EU

The European Patent Convention of 1973 established the basis for the European Patent Organization, which is in charge of granting and overseeing patent application procedures through its European Patent Office (henceforth, EPO)[8]. Today the European Patent Organization has 38 member states and 2 extension states. The organization provides information on patent applications and grants by technology classes, applicants' country of residence and over the years[9]. EPO patents are not domestic: Granted patents by the EPO are not single patents, constitute separate patents for the member countries where they are claimed. As elaborated by Le Bas and Sierra (2002) the grant procedure followed by EPO provides EPO patents with several important and distinctive characteristics; for example, higher patent fees that act like economic filters for higher value innovations, and the absence of a domestic effect emanating from domestic evaluation processes.

Based on the EPO statistics, patent applications have grown from 135,358 in 2006 to 160,022 in 2015, non-monotonically, with 2009, 2011 and 2013 exhibiting some decline in the number of applications. Considering that there were a total of 391,440 patent applications to the EPO during the 1985-1992 period[10], these numbers reflect an immense growth in the number of applications to the EPO. The decline in the grant rates in 2009 and 2010 has been attributed to the financial crisis, during which applicants were economizing on their patent budgets and allowed their applications to lapse in examination (Harhoff, 2016). For European inventors, level of education, employment in a large firm and involvement in large scale research projects have been shown to positively correlate with the number of patents an inventor produces (Mariani and Romanelli, 2007). Furthermore, a team of scholars using patent data from European firms reports a strong positive correlation between the stock of patent applications and stock of exports (Frietsch et al., 2014). These findings indicate that total patenting in Europe may depend on firm specific as well as macroeconomic and systemic factors.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Applications	135358	141231	146244	134511	151015	142822	148562	148027	152703	160022
Grants	62777	54700	59800	51952	58117	62108	65655	66707	64613	68421
Grant Rate	0.4638	0.3873	0.4089	0.3862	0.3848	0.4349	0.44194	0.4506	0.4231	0.4276

Table II. Total number of applications and grants to the European Patent Office

It should be noted that a sizeable amount of innovations remains without patent protection. Based on a survey-based measure of patent propensity, Arundel and Kabla (1998) found that patent propensity rates, i.e. the likelihood of a firm to patent its product or process innovations, were subject to considerable variations across industries in Europe (Table 1, p.

[8] https://www.epo.org/law-practice/legal-texts/html/epc/2016/e/index.html
[9] All of these statistics are available online on EPO website: https://www.epo.org/about-us/annual-reports-statistics/statistics.html#filings
[10] Number of applications reported by Guellec and de la Potterie (2000), p.111.

133), with only four industries having patent propensities above 50%. The study also notes that process innovations are less likely on average to be patented due to difficulty in observing infringements, and they also find that the patent propensity of a firm increases together with its annual sales (p.134). Besides the variation across industries, innovative activity by large firms is also concentrated in some regions of Europe, which is interpreted as evidence for the importance of technical capabilities in the decision of multinational enterprises to locate their R&D activities (Verspagen and Schoenmakers, 2004).

4.1.3 China

In China, filing, processing, and granting patent applications are carried out by the State Intellectual Property Office of the People's Republic of China (SIPO).

According to 2015 statistics of the SIPO, a total of 1,101,864 invention patents were filed in the People's Republic of China, with 359,316 patents being granted over the same year, based on the 8 main classifications of inventions by the IPC system[11]. These numbers reflect a 18.71% increase over the 928,177 invention patent applications of 2014, and an increase of 54.06% over the 233,228 invention patent grants of 2014. Considering that the SIPO received a total of 879,025 invention patent applications over the 1985-2005 period from domestic and foreign applicants, 2015 figures stand out in stark contrast: Over the 1985-2005 period, 442,829 (50.38%) invention patents were filed by domestic applicants, while the remaining 436,196 invention patents (49.62%) were filed by foreign applicants. Among these 879,025 invention patent applications received between 1985-2005, 238,717 invention patents were granted (27.16% grant rate), with 87,365 (19.73% grant rate) of them granted to domestic applicants, and 151,352 (34.7% grant rate) of them granted to foreign applicants.[12]

The recent surge in patenting activity in China stimulated research efforts to explain the underlying reasons for the increase. The results of Hu and Jefferson (2009) suggest that the increase in patenting activity is a result of the increasing foreign direct investments that China received. Further, the authors also associate the surge in patenting activity with China's accession to the World Trade Organization (WTO) in 2001, and with a clarification of intellectual property rights in the wake of amendments to the patent law in China. Hu (2010) instead, considers two possible reasons for the surge in patenting activity in China: an increase in the deployment of new technologies and a reaction to competitive threats. He finds support for the latter. Accordingly, the increase in patenting stems from strategic preemption, and from an effort to block the entry of possible competitors in the Chinese market. Another study focuses only on invention patents (as opposed to invention patents, utility models and designs altogether) and finds that the surge in patenting activity has been dominated by a small number of firms that are operating in the information and communication technology (ICT) sector (Eberhardt et al., 2016). According to the results of

[11] Industry breakdown of the patent grants can be found in the following link: http://english.sipo.gov.cn/statistics/2015/12/201601/t20160115_1229456.html
[12] Number of applications and grants from 1985-2005 were calculated from the following table: http://english.sipo.gov.cn/statistics/200804/t20080416_380885.html

same study, the increase in patenting in China does not originate from a genuine increase in the underlying innovative behavior, but from a shift in the incentives of firms to file for patents so as to qualify for governmental subsidies. The explanation pointing to a shift of incentives due to governmental subsidies, is corroborated by the findings of other studies (Dang and Motohashi, 2015; Li, 2012). Dang and Motohashi (2015) report that these subsidies could account for about 30% of the increase in patent counts in China. In a similar vein, Li (2012) finds that province level patent subsidy programs increased patenting activity not only for firms, but also universities, research institutes and individuals and not only to the domestic patent office, but also to the EPO and USPTO. Furthermore, based on the ratios of granted patents, the study does not find evidence for a decrease in patent quality as the number of patent applications increase. There is further evidence suggesting that the subsidy programs in China is also linked to the increase in the university patenting in China (Fisch, Block and Sandner, 2016). Overall, the literature suggests that governmental subsidies were a key factor leading to the patent boom.

It is noteworthy that the surge in patenting activity largely coincides with the boom in scientific journal publications in China. The boom in scientific output has also been associated with governmental support to the development of science and technology in China, as part of a larger commitment to transform China into a knowledge-based economy (Zhou, Leydesdorff, 2006).

4.2 COSTS OF THE SYSTEM:

4.2.1 Litigations

The patenting process is itself costly and complex, as it requires expertise to frame the claims and coverage of the patent protection. But enforcing patents, discovering the infringement done by other parties, and constantly watching for new infringements is also difficult. These complexities generate a gap between the formal protection of a patent and a practical protection of a patent (Eisenberg, 2011). As an example, infringements on process innovations are notoriously difficult to trace and take to a court (Arundel and Kabla, 1998). There is considerable variation across patents in terms of their litigation risk; for high value patents, with high number of claims and forward citations per claim, the probability of litigation can be quite high, to the extent that R&D incentive emanating from patent ownership may disappear (Lanjouw and Schankerman, 2001). Based on event studies of firms in information technology industry, Raghu et al. (2008) finds that patent litigation has a significant negative impact on the defendants, whereas the effect is significantly positive for plaintiffs. Moreover, according to the findings of the same study, patent litigations in the information technology do not result in a zero-sum, but a negative sum.

There is evidence showing that there is substantial variation across areas where patent oppositions take place (Harhoff and Reitzig, 2004). According to this, patent oppositions occur in high value patents and in areas of high technical and market uncertainty. A recent study assesses the impact of the newly introduced post-grant review system in the US, by matching US patents to equivalents among EPO patents based on observable characteristics, and finds that opposition rates are three times higher among EPO-equivalents of US litigated patents, compared to non-litigated patents (Graham and Harhoff, 2014). Beyond oppositions, there is substantial concentration of patent lawsuits in urban areas in China, and the rates of success for those suing the infringers are similar to those in the US (Love et al., 2016).

With millions of active patents and hundreds of thousands new patents filed for every year, it is difficult for any single firm to keep up with the state-of-the-art, especially in fast moving industries (Lemley and Feldman, 2016). These authors note that the majority of patent lawsuits are now filed by non-practicing entities since it is difficult to observe non-practicing entities' patent portfolios in such a dense patent landscape. According to a recent study using event study method to look at cumulative abnormal returns around the time when non-practicing entities file for patent lawsuits, non-practicing entities may have caused the loss of half a trillion dollars in market value between 1990-2008 period (Bessen et al., 2011). Moreover, this represents a huge loss in R&D incentives and in social welfare as only a small amount of money transferred from the sued parties ends up in the non-practicing entity.

4.2.2 Patent delay

There is evidence showing that well-documented applications are approved faster by the EPO, but withdrawn more slowly by the applicant (Harhoff and Wagner, 2009). According to the results of the same study, patent applications with higher value, where value is measured by patent citations, patent family size and the number of claims, are approved more quickly by the EPO, and are withdrawn by the applicant more slowly. Based on a longitudinal study of patents on genetically modified crops in the US, Regibeau and Rockett (2010) finds that examination delay decreases as the patent office examines more patent applications in a technology class, and that the review delay is shorter for more important patent applications (i.e. patents that receive more citations) when the date of filing is controlled for.

When an inventor files an application for a patent, some information about the patent that is applied for is disclosed in the patent bulletins or gazzete, well before mandatory disclosure at the eighteen month after the application date. If the patent office evaluates a present application after the eighteen month period passes, there is a period of time between the application date and the mandatory disclosure, during which an applicant has a pending patent application with limited information about it released to the public. It has been discussed that there may be strategic value for firms to file for patents and gain the title of a patent applicant in a novel technology class, even if the applicant knows that they are not filing for a novel patent and the application will invariably be rejected (Koenen and Peitz, 2015).[13]

Delays in patent allowance have far-reaching consequences, as the intellectual property rights associated with a patent are tradable before the patent is granted. As we also mentioned above, there is evidence showing that the probability of achieving a cooperative

[13] Patent Offices have taken up the issue of inflationary application numbers of seemingly weak patents by proposing early certainty programs. These rely on an early search and preliminary opinion of the patent application being made available to the public (http://blog.epo.org/patents/early-certainty-from-search-one-year-on/).

licensing agreement significantly increases in the aftermath of a patent allowance, as the allowance removes the uncertainty regarding the intellectual property that is negotiated (Gans, Hsu and Stern, 2008). The problem generates a friction in the market for ideas and is aggravated for industries where alternative appropriation mechanisms are non-existent. According to Farre-Mensa et al. (2016) each year delay in reviewing a firm's first patent application that is eventually approved reduces the firm's employment and sales growth over the five years following approval by 21 and 28 percentage points, respectively.

4.2.3 Other problems

Besides these two main issues that have attracted researchers' interest, other problems of the patent system have been discussed in the literature. There are social costs of the patent system beyond the problems associated with the infringer and the patentee. Although patented innovations generate exclusivity to the inventors and generate incentives for innovation, in pharmaceuticals, the patent rights may generate problems associated with life-saving drugs (Hoen et al., 2011). In other words, the exclusivity offered by patents, may turn out to be a death sentence for some people in the society.[14] In some areas, exclusivity of a patent may block others from accessing key knowledge crucial for further developments in the field. Patent pools, where owners of patents agree to license their patents to each other or to other parties, have been offered as a solution to tackle some of these problems (Clark et al., 2000).

Beyond the number of patents, the content of patents has created discussion. As patent applications became longer and include more and more claims, patent offices started to take up the issue. As reported by Harhoff (2016), the measures introduced by EPO seem to have curbed the gradual and sustained increase in the number of claims and the amount of content in patent applications.

Boundaries of patentable innovative activity are established by the patent law in every country, along with the conventions and legal requirements of patent offices. It is worth noting that changes in the broader legal system have generated conflicts on the boundaries of patentable activity, with interest groups and non-governmental organizations getting involved in legal processes.[15] Patents on natural phenomena, although only available once isolated with specialized processes, have generated long legal disputes. Rosenfeld and Mason (2013) suggest that about 41% of human genome has been claimed in patent applications up to their time of analysis. Cartwright-Smith (2014) argues that the research activity has suffered due to monopoly rights associated with patents granted on human genomes. The limits of patentable activity was a topic also for software patents, where the generic implementation of an patent-ineligible abstract idea has been denied a patent.[16] Again on the limits of patentable innovations, Scotchmer (1996) suggests that limits on

[14] "Meet the guy behind the $750 AIDS drug", CNN, September 22, 2015. http://money.cnn.com/2015/09/22/investing/aids-drug-martin-shkreli-750-cancer-drug/

[15] Verdict in the Brüstle vs. Greenpeace Case, Summary of a long standing legal dispute http://www.stemcells.nrw.de/en/latest-news-press/latest-news/details/article/urteil-in-der-streitsache-bruestle-vs-greenpeace.html

[16] U.S. Supreme Court Ruling on the case of Alice Corporation Pty. Ltd. vs CLS Bank International *et al*. Available on: https://www.supremecourt.gov/opinions/13pdf/13-298_7lh8.pdf

patents that are granted on second-generation products could protect early inventors and engender investments in more basic technologies.

5 PATENTS IN ICT

5.1 PROBLEMS IN ICT

Digitization has fundamentally transformed the information and communication technology (ICT) industry more broadly. The technological change has been accompanied by a dramatic increase in the use of patents, and escalating patent enforcement, both of which have resulted in outright `Patent Wars'[17]. Several interrelated factors explain this shift towards patenting in ICT: First, there has been a global patent explosion (Kortum and Lerner, 1999; Fink et al., 2013), perhaps most notably in China (Eberhardt et al., 2017). According to WIPO data, the combined share of the top 5 ICT fields on the total number of patents filed worldwide went from 18.8% in 1995, to 28.9% in 2013[18]. Second, there is an overall increase in the level of technological complexity and the convergence of different technological domains. The increased complexity and combination of different types of technologies result in a high degree of interdependency between different components of a given technology. This complexity has led to overlapping claims across patents in ICT, and this situation can result in patent thickets if patent ownership is diffuse (Shapiro, 2001). The more complex technologies are, the more prevalent are such thickets (von Graevenitz et al., 2011). Third, the need for interoperability and interconnectivity of different technologies and devices to combine them into single products and services creates demand for technological standards that promote compatibility (David and Greenstein 1990). While such standards, in principle, allow to link different products and technologies by different producers, such standards also involve patent rights, providing additional incentives to patent strategically (Berger et al. 2012, Kang and Bekkers, 2015) and define standards accordingly. Similarly, firms seek to establish alternative mechanisms to structure the patent jungle. Patent pools and cross-licensing agreements are popular solutions, but they have the obvious drawback that in order to participate, firms need patents.

Patenting propensities in ICT display an even more pronounced increase than other industries. The patents-R&D ratio (patents per 1992 US$ million) increased from around .4 in 1987 to .9 in 2000 (for comparison, the increase in semiconductors was from .3 to .6 over the same period (updated Figure 1 of Hall and Ziedonis (2001)). Based on more recent data covering 13 OECD economies, Fink et al. (2013) show that patenting propensities in ICT continued to climb during the 2000s. Fink et al. (2013) also show that the relative increase in

[17] "The smartphone patent wars" by Oberlander M., Stabe M., Bernard S. October 17, 2011. Accessed on 28/01/2017. Available at:
http://www.ft.com/cms/s/2/de24f970-f8d0-11e0-a5f7-00144feab49a.html?ft_site=falcon

[18] Patent figures from WIPO, accessed on 28/01/2017. Available at:
http://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2015-part1.pdf

patent filings in ICT is partly due to an extremely fast growth in filings on digital communication technologies.

5.2 Problems in dynamic sectors

Using numerous case studies and a survey among German software companies, Blind et al. (2005) provide important evidence on the functions of patents in the software sector. Several conclusions can be drawn from the study, on the role of patenting activity and the patent system in dynamic sectors like ICT.

On the one hand, the disclosure function of patents is less effective in promoting the diffusion of knowledge and generating sequential innovations in the ICT sector. There is reason to believe that small enterprises are wary of disclosing innovative ideas in patent documents, due to the presence of stronger competitors that can assimilate and successfully market the ideas that are disclosed in patent documents. Consequently, neither an increase in market transparency nor a reduction of transaction costs was observed. On the other hand, the incentive function of patents – especially towards radical innovation - in terms of expanding the protection strength and the protection period for companies' know-how, does not work in ICT. However, evidence shows that patents help start-up companies in raising venture capital and in protecting themselves against the power of large firms in the market and against staff members who leave the enterprise and transfer their know-how with them (Mann and Sager, 2007).

In summary, the effectiveness of the virtues of patenting is limited in the ICT sector and particularly for software companies. However, Eberhardt et al. (2016) report a positive impact of a proposed broadening of patent eligibility to include software in 2004 on the performance of software companies listed in India. The authors also report a negative impact of an unanticipated reversal of this proposed policy change in 2005. Finally, smaller firms have been systematically and most significantly affected by the tightening of patent law on software patents. More generally, the institutional and cultural context plays a significant role on how virtues of patents play out in the software sector.

In contrast, the drawbacks of patents for companies active in ICT in general, and software in particular, are quite severe. First of all, patents are not oriented towards the idiosyncrasies of the sector, especially due to the difficulties in determining the very dynamic and complex state of the art triggered by complementary developments. In line with the theoretical framework of Bessen and Maskin (2009), open source companies and developers complain that banning the use of protected algorithms hamper incremental and sequential development work. Thus, patents reduce the variety and interoperability of products and harm the open-source movement. A multiplicity of applications and further developments can be blocked by patents, slowing down the speed of innovation in the entire software sector due to an increase in development costs (Bessen and Hunt, 2007). In a similar vein, the solution of the theoretical model of Hunt (2004) in rapidly innovating industries suggests that the optimal patenting standard maximizing the innovative outcome at the industry level is attained when a smaller share of innovations qualify for patent protection.

Overall, the software companies investigated by Blind et al. (2005) complain that the patent system leads to misallocation of resources, due to the emergence of alternative designs for functional equivalents and interoperable applications, and more resources allocated to legal dealings instead of R&D (see above section 4.2).

Furthermore, the above-mentioned drawback due to extreme monopoly power arising from patents may be aggravated by the presence of direct and indirect network effects in the ICT sector. The dominant position of companies in the ICT sector achieved by owning large patent portfolios, establishing dominant platforms (Eisenmann, Parker and Van Alstyne, 2011) or influencing standards development (Baron et al. 2016), provides further support to this view.

Finally, the great majority of the companies interviewed by Blind et al. (2005) expressed their confusion about the criteria for granting patents in the software area, and pointed to difficulties in obtaining data on granted patents relevant for their enterprises in the software area. This suggests that in dynamic sectors, patents may also create some legal uncertainties.

6 PROPOSED SOLUTIONS TO PATENT DRAWBACKS WITH A SPECIAL FOCUS ON ICT

6.1 PATENT POOLS

Patent pools are agreements between two or more patent owners by which they put their patents together, and in return receive a license to use them, or, sometimes, license them as a bundle to third-party non-member firms (Lampe and Moser, 2016). A recent EC study describes a patent pool as an "instrument to develop and deploy technical solutions in fields with a public/social need"[19]. The ultimate goal is, therefore, to collect all patents that are important for developing an innovation, and use them in the interest of pool members and the society as a whole. Thus, pools are a mechanism to resolve patent wars over technologies, whereby competing firms own mutually infringing patents, or to facilitate innovation by lowering the transaction costs of licensing and by preventing double-marginalization (or "royalty stacking"), which occurs when individual firms charge excessive license fees for complementary parts of the same technology (Merges, 1999). There is some evidence showing that patent pools are associated with reduced prices in the downstream product market (Kim, 2004).

In the ICT sector, patent pools are often built around technical standards, arising from the aggregation of those patents that are essential for the technology, referred to as standard-essential patents (SEPs) (Lerner and Tirole, 2014; 2015). Standard essential patents are of

[19] Report of the Expert Group on Patent Aggregation by Giuri et al. 2015. Available at: https://ec.europa.eu/research/innovation-union/pdf/expert-groups/report_of_the_expert_group_on_patent_aggregation_-_2015.pdf

particular value to companies, as shown by Rysman and Simcoe (2008), because via the implementation of the standards, royalty revenues are increased (Pohlmann et al. 2016), although the effect is contingent on the licensing regime (Hussinger and Schwiebacher 2015). Furthermore, infringement can be more easily inferred from the use of the standard.

Although there are obvious benefits to technology standards (above all compatibility and interoperability), the role of SEPs has been more controversial. For example, Blind et al. (2011) offer survey evidence that shows that participants of standard setting organizations consider SEPs to make it harder to reach consensus and slow the standardization process. Companies that do not own SEPs indicated that they encounter problems while negotiating on licensing conditions. Kang and Bekkers (2015) argue that SEPs are often the outcome of strategic insertion of patents into the standard, despite little technological value of these patents to the standard.

Perhaps more importantly, patent pools can create market power that goes beyond the patents, but that derives from the standard. This is especially problematic when a large portion of innovations is coming from small firms that are outside the pool. The EC guidelines (TTBER Guidelines 2014),as the TTBER (TTBER 2014) itself does not cover technology pools, emphasize that patent pools built around technical standards should include only essential technologies and complementary technologies, and when patent pools have a strong position in the market they should be open and non-discriminatory. Most importantly, they have to commit to a licensing price based on (F)RAND (fair, reasonable and non-discriminatory) terms. While these conditions help to make the patent pool pro-competitive, even (F)RAND licensing obligations often do not solve the issue, as frequently disputes about the actual (F)RAND royalty rate erupt (Lemley and Shapiro, 2013). Moreover, royalty stacking might also occur if ownership of SEPs on a given standard is split across multiple patent owners.

The evidence about the impact of patent pools is mixed. Lampe and Moser (2016) focus on patent pools in traditional industries (nonstandard) where antitrust rules were not effective. They find that the creation of pools has a negative impact on innovations, measured as the number of patents. They suggest that the mechanism behind this decline is that firms compete less aggressively on R&D. However, research focusing on modern patent pools (standard) has offered different findings. Vakili (2016) shows that the formation of seven major modern patent pools in ICT related areas has, on average, increased the rate of follow-on innovations based on the pooled standards by about 14%. He suggests that patent pools can facilitate a shift toward vertical disintegration in associated industries where upstream technology-focused organizations would disproportionally contribute to the development of follow-on complementary technologies.

6.2 Cross-licensing (voluntary ex-ante licensing)

Cross-licensing agreements between companies grant each involved party access to agreed-upon IP rights owned by other involved parties. Usually, cross-licensing agreements involve a reduced number of firms compared to patent pools and are not geared to grant access to third parties (Regibeau and Rockett, 2011). Thus, cross-licensing agreements are well suited to provide freedom-to-operate when key patents are controlled by different companies, but the fragmentation of the patent landscape is not excessive. Köhler (2011) empirically shows that technological interdependency is the key factor that motivates German companies to engage in cross-licensing transactions. Small firms might be more prone to the use of cross-licensing in order to secure the freedom to operate.

The literature distinguishes between ex-post agreements, where the innovation involved has already been developed (even if protection has not yet been obtained) and ex-ante agreements, which are based on the commitment to share all or some future-IPRs within some fields of research.

In the ICT sector, cross-licensing agreements may increase incentives to innovate when they allow a better and more efficient use of the fragmented knowledge. Similar to patent pools, they can benefit the interested parties by offering enhanced design freedom by virtue of providing access to others' patent portfolios (Shapiro, 2001). Cross-licensing agreements might also reduce costs associated with litigation and the risks of imitation.

Nevertheless, cross-licensing agreements might have significant anticompetitive effects. Cross-licensing agreements have been used in the past to sustain collusion (Arora et al., 2001) and theoretical models support the notion that cross-licensing might favor tacit collusion by increasing the punishment in case of defection (Eswaran, 1994). The risk of tacit collusion is higher when firms cross-license substitute patents (Regibeau and Rockett, 2011). Alternatively, firms might use cross-licensing agreements to artificially increase their marginal costs and thus commit to a higher price in the market.

Empirical evidence on the impact of cross-licensing on innovation and on the effectiveness of cross-licensing in addressing the problems associated with fragmented patent landscapes is almost non-existent.

6.3 Patent Pledges

Patent pledges are commitments to limit the rights granted by patents. A patent is a legal right to exclude the exploitation of an invention in a territory. The patent holder may though decide to impose certain limitations to its right for many different reasons and purposes (Contreras 2015), for instance to induce other actors to certain behaviors such as adopting an interoperable standard including patented technology, promoting the leadership of a technology over competing alternatives or fostering the development of a market. Another reason could be to engage in a collective action that would provide a benefit to a group of actors if a commitment is made by all of them, for instance, the commitment not to sell patents to NPEs (Non-Practicing entities). Finally, patent pledges could be done to improve corporate image, or to overcome potential antitrust issues.

Patent pledges allow to overcome the exclusionary aspect of patents and to emphasize their role as a tool for the diffusion of knowledge for the benefit of the society. To this regard the patent system does not provide universal procedures to waive some of the rights granted by patents (Chien, 2015), and thus patents usually default to exclusion, which is a tool of the system rather than its ultimate goal.

In addition to this lack of a systematic approach to patent pledges, another significant barrier is their reliability, and the perception of their reliability by the industry. Since there is not a well-known and proven mechanism to waive rights, there is some uncertainty in the industry as to the extent to which these commitments are legally binding. One of the issues is the lack of an official or widely recognized license or contract to waive rights. Another aspect is the lack of an official registry of patent pledges (Contreras, 2015) or a universal way to register these commitments in patent records. Thus, the potential beneficiaries of the pledge do not have an official registry to check these commitments, nor are they confident that commitments they made through different means (press releases, blogs, etc.) are going to be permanent. Moreover, there is usually a lack of information as to whether the commitment is inherited by any potential successor of the patents, be it by means of the patent being traded, merge & acquisition operations involving the original patent owner, or other situations. These aspects increase the legal uncertainty of patent pledges, and thereby decrease their value as a tool for the diffusion of knowledge.

6.3.1 Non-assertion covenants

Non-Assertion Covenants (NACs) are agreements by which a party restrains its ability to seek the enforcement of a patent, or of any other type of IPR, against another party or parties (Bekkers, Iversen, and Blind, 2006). NACs may limit the exemption from enforcement to a specific time frame, geographic area or field of application. The most frequent application of NACs is as part of licensing agreements or as part of a settlement involving a patent infringement, with the purpose of preemptively addressing future disputes (Iversen *et al.*, 2006).

Together with patent pools and voluntary ex-ante licensing, non-assertion covenants are increasingly used to address the limitations of the (F)RAND licensing agreements that are almost universally required by SSOs for the inclusion of a technology into the standard promoted by the organization (Bekkers et al., 2012; Maggiolino et al., 2015). The adoption of (F)RANDs in fact, has come under scrutiny after a surge in legal actions between firms adhering to SSOs. For example, in 2005 Nokia and five other companies filed a complaint against Qualcomm in front of the European Union Commission for excessive royalties. Contentions over FRAND are in general found at the center of most litigation cases between telecom firms in the last two decades.

A major step for the diffusion of NACs as a means to prevent litigations related to (F)RANDS disputes has been their direct inclusion into the IPR policy of the OASIS Consortium (Organization for the Advancement of Structured Information Standards) . The OASIS Consortium is a standard body that includes representatives from the major ICT firms with large patent portfolios. The new policy of the consortium, which went into effect in 2009, formally includes NAC arrangements options as potential set-ups to adopt during the standardization process.

Furthermore, at times NACs can also be signed unilaterally by a firm with the intention of promoting the diffusion of its technology or with the intention of signaling goodwill toward a particular community. For example, in 2005 IBM signed a NAC concerning 500 of its U.S. patents in favor of users and developers of the Open Source Software community (OSS). By doing so, it improved its public image, and addressed concerns regarding freedom to operate in the field, and reduced the transaction costs of innovators in the area. For instance, Wen, Ceccagnoli and Forman (2015) find that IBM's actions stimulated new OSS product introductions by entrepreneurial firms and that their impact is increasing in the cumulativeness of innovation in the market and the concentration of patent ownership in the market.

Finally, geographically restricted NACs are also prosed by the WIPO as a way through which companies could help in resolving humanitarian crises without completely renouncing their legal rights regarding valuable patents. For example, according to a WIPO report (Krattinger *et al.*, 2010), access to dengue vaccines could be greatly improved by Sanofi Pasteur signing a NAC concerning one of its patents related to vaccine administration only limited to low-income countries.

6.3.2 Commitment to license (License of Right, FRAND, etc.)

The limitation of the exclusionary aspect of patents in favor of a willingness to license the patent appears as a way to overcome some of the fragmentation problems mentioned previously.

The EPO's report, Scenarios for the Future (EPO, 2007), envisaged a hypothetical future scenario, the so-called 'Blue skies' scenario, in which some specific technologies, such as in ICT, or challenges, such as environmental issues, would require wider technology diffusion and more collaborative innovation whilst avoiding issues such as patent thickets. The report promotes a dual IP regime, in which the former cases could be linked to a softer IP regime under which patent holders would no longer be able to block the use of a technology but instead they would be obliged to license it to any user under specific conditions and fees.

Another less hypothetical case happens in the realm of standardization. (F)RAND ((Fair) Reasonable And Non-Discriminatory) terms, is a commitment required by most SSOs (Standard Setting Organizations) to avoid the hold-up problem (Lemley, 2007), that is, the request of disproportionate royalties by holders of standard essential patents once the industry has made irreversible investments. Hold-up situations are particularly problematic whenever industry players make an effort in order to converge toward a technological standard. This entails both the loss of the opportunity to develop an alternative standard and the loss of the opportunity to develop a product that is compliant with the patented technology.

The WTO's TRIPS agreement (TRIPS, 1995) introduces the option for governments to adopt Compulsory Licensing, that is, licensing a patent without the consent of the patent owner under certain exceptional conditions linked to public interest, and mainly for the protection of public health, as clarified in the subsequent Doha's "Declaration on the TRIPS Agreement and Public Health" (TRIPS Doha, 2001). As an additional step forward that is also related to the ICT sector, Geiger and Hilty (2005) propose to have compulsory licensing for software patents.

A voluntary version, known as "License of Right" (LOR) is present in the patent legislations of some countries, such as Germany, providing the means for the patent owners to willingly declare to the Patent Office that they are prepared to allow anyone to use the invention in return for a reasonable compensation. There is usually a value linked to the exclusivity right (Rudyk, 2012), which is foregone by the License of Right declaration, and that is why the

Patent Offices usually compensate applicants using this declaration with a partial exemption of maintenance fees, for instance, with a 50% reduction in Germany.

6.4 Patent aggregators and patent-assertion entities

For a patent to be granted, the innovation contained in it needs to be new and non-obvious. Unfortunately, these same characteristics that contribute to increasing the value of the legal rights afforded by the patent also impair the working of any large scale market aimed at the exchange of technology (Gans and Stern, 2010). There can be no standardization and no standard price set by the market as patents are not comparable to one another. As a consequence, the global market for IPR consists of many bilateral, and few multilateral, transactions where the price for the exchange of the technology is privately negotiated between the parties. Illiquid markets presenting these characteristics also afford many profit opportunities for intermediaries, whose value proposition consists of resolving part of the uncertainty surrounding transactions and facilitate the exchange of IPRs.

The existence of intermediaries is not new, as patent brokers, for example, have existed at least since the nineteen century (Lamoreaux and Sokoloff, 2003). Nevertheless, in recent years lawsuits due to a special type of intermediaries, Patent Assertion Entities (PAEs), have taken a surge. In 2015 for example, 66.9 percent of the total number of lawsuits were brought about by PAEs (*Patent Dispute Report*, 2015). The litigation risk associated with PAEs is especially high for firms operating in the ICT sector. According to a Federal Trade Commission report (FTC, 2016)[20], in fact 88% of the patents held by PAEs are classified as ICT patents. This increase in lawsuits has spurred firms to look for potential solutions such as the already-mentioned patent pools, especially related to standards released by SSOs. In addition to these, Patent Aggregators are a new means to reduce the uncertainty surrounding a technology that is becoming increasingly adopted by firms.

Hagiu and Yoffie (2013) distinguish between two types of patent aggregators. The first is Defensive Patent Aggregators. The category is exemplified by firms such as RPX and Allied Security Thrust. The core business of these patent aggregators consists of offering an incomplete insurance policy against the risk of patent trolling to their subscribers, which are large firms of the caliber of eBay, HTC, and Panasonic[21]. These firms pay an annual insurance fee that varies depending on the operating income of the subscriber. In exchange, the aggregator identifies those patents that might threaten its subscribers, acquires them, and provides its subscribers with a license to those patents. From the economics point of view, the advantage afforded by defensive patent aggregators seems difficult to quantify.

Unlike traditional insurers who cover the cost of the damage once it has happened, their service consists merely in the reduction of the probability that the damage will happen.

[20] Accessed on 28/01/17. Full report available at: https://www.ftc.gov/reports/patent-assertion-entity-activity-ftc-study

[21] The strategy of the two firms is different though. RPX allegedly uses a catch-and-hold strategy by retaining the patents they acquire and attracting new paying members with their portfolio. AST, on the contrary, uses a catch-and-release paradigm, wherein the bought patent is first licensed to all members and later released for monetization purposed.

Alternatively, they can be seen as a more efficient way of acquiring the right to the intellectual property protected by patents. In this case, the benefit of defensive patent aggregators is the greatest in the presence of high IPR fragmentation and in the presence of many patents of marginal value that are not worthy of acquiring, but that might be used as a weapon in a lawsuit.

The second category of aggregators is known as Super Aggregators and is more controversial than the first. This category is epitomized by Intellectual Ventures, the company founded in 2000 by Microsoft's former CTO, Nathan Myrhvold. Super aggregators are a hybrid between a defensive aggregator, a PAE, and a "weapon dealer" who can provide IPR to the litigants in a lawsuit. For its double role, Intellectual Ventures has been at times described as the "world's largest patent troll" (Orey and Herbst, 2006). Unlike defensive aggregators, Intellectual Ventures is also directly involved in the production of knowledge through several partnerships with scientists. Nevertheless, the knowledge generated internally is then exploited through licensing agreements rather than through internal development. On the governance side, super aggregators suffer from a tension as their investors include both firms interested in the patent portfolio of the aggregator for strategic reasons, as well as pension funds and financial investors whose interests would be better served by the aggressive pursuit of lawsuits. The business model is also extremely risky as it involves the stock purchase of large patent portfolios. By Intellectual Venture's own estimates, 19 out of 20 of the patents they acquire turn out to be of poor quality (Hagiu, Yoffie, and Wagonfeld, 2011). Nevertheless, the large scale of aggregators like Intellectual Venture helps in reducing the information asymmetry and transaction costs that characterize the IPR marketplace by providing a one-stop shop for buyers and sellers of a technology.

For what concerns specifically the ICT sector, the existing literature is polarized. Some authors claim that the presence of PAEs and patent aggregators is just a symptom of the systemic problems that characterize the ICT patenting landscape. According to Lemley and Melamed (2013) these problems include an overabundance of patents that are interpreted too broadly, a legal system that allows patent holders to obtain excessive settlements, and an important royalty-stacking problem. Other authors instead emphasize the positive role played by PAEs and aggregators in the ICT market. Shrestha (2009), for example, argues that by identifying and acquiring valuable patents that are then licensed to practicing firms, PAEs reduce the IP monitoring cost and encourage innovation. Consistently, Fusco (2016) argues that PAEs and aggregators also create a secondary, liquid, market for small inventors that otherwise wouldn't have the resources to both innovate and pursue infringers (Conrad, 2007).

6.5 Auctions and Patents as consumable assets in patent exchanges

Spurred by the surge in trade volume of secondary markets for patents, some patent licensing and patent property transaction models have tried to mimic the trading of more traditional categories of assets. Patent auctions have taken place, like for instance those organized by Ocean Tomo. Some have even proposed patent indexes as a metric for the knowledge economy[22]. Over the last decade or so, the heydays for auctions appear to have passed, mainly due to negotiation imbalances where the demand-side seemingly has the upper hand. However, patent auctioning has made a significant comeback.

A few scholars have proposed the creation of patent exchanges (e.g. Ghafele and Gibert, 2012), with IPXI a notable example. In doing so, they have taken on the challenge of defining new asset categories that would be best suited for trading. Interestingly, proponents of this solution advocate that the asset to be traded must be commoditized and must be made a consumable. This would then put patents close to trading commodities such as wheat or oil. The traded asset would imply a standardized license to sell, manufacture or import a limited number of products. The patents would need to first be bundled and mapped into specific products. Standardized licensing rights (ULR, Unit license rights) would be publicly offered. Price discovery would be limited to initial offerings, while offering in tranches would allow a transparent process. The advantage of such systems is that efficiency would increase dramatically, as most of the overhead in bilateral negotiations would become redundant. Additionally, access to a technology would, in principle, be fair for all parties, as any implementers, big or small, would have access to the same kind of contractual conditions.

Unfortunately these initiatives have encountered significant difficulties in the implementation phase. For example, the initial launch of IPXI failed because the program did not receive sufficient interest from investors (Contreras, 2016).

7 CONCLUSIVE REMARKS

The Patent System, established more than a century ago to provide incentives to create and diffuse new ideas and technologies, has been subject to many criticisms in recent decades. Changes in the innovation process, the increasing complexity of technologies, the strategic behaviors of companies in applying for protection have, among other factors, questioned the very same nature of the Patent System. This work has made a systematic review of the existing theoretical and empirical research that either supports or contests the well-functioning of the current Patent System. In addition, this research describes and assesses the main solutions that emerged in recent years in response to the inefficiencies caused by the proliferation and fragmentation of patent rights, a problem that is particularly salient in ICT. Overall, it contributes to a better understanding of the issues at stake and helps set the ground for advancing workable proposals to improve the current status quo.

[22] Ocean Tomo 300 Patent Index. Accessed on 28/01/2017. Available at: http://www.oceantomo.com/ocean-tomo-300

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