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THE ROLE OF PATENTS IN INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTS). A SURVEY OF THE LITERATURE.

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The Role of Patents in Information and Communication Technologies (ICTs). A survey of the Literature.[1]

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Abstract

During the last decades, the number of ICT related patents has increased considerably. In association with a great fragmentation in IP rights, the increasing number of patents has generated a series of potentially problematic consequences. Patent thickets, royalty stacking, the emergence of patent assertion entities, increased patent litigation – in particular around standard essential patents – and the difficulties in the definition of fair, reasonable and non-discriminatory (FRAND) licensing terms are among the most debated issues in the literature that we review in this paper. We devote a specific section of our survey to patents involving software products, where the above problems are amplified by the high level of abstraction of computer algorithms. In our analysis we mix theoretical and empirical arguments with a more policy-oriented reasoning. This allows us to better position the different issues in the relevant political and economic context.

1. Introduction

The dynamics of the knowledge economy in today's globalized markets and the increasing complexity of products have radically modified firms' intellectual property (IP) strategies and have led to an enormous growth in the number of patent applications. The proliferation of patents and their increasing fragmentation have produced a series of consequences – patent thickets, royalty stacking, augmented litigation, difficulties in the definition of licensing terms for patents related to standardized technologies... – that are seen as potentially problematic. In this paper, we survey the economic literature on the role of patents in information and communication technologies (ICTs)

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where much of the surge in patenting has taken place and where these changes in the IP landscape are most striking.

ICTs – intended as the set of technologies aimed at processing, storing and transmitting information (including telecommunication equipment, consumer electronics, computers and software products) – are among the most dynamic and innovative segments of modern economies. They now permeate all aspects of our everyday life, impacting virtually all the sectors of the economy. ICTs are changing the way firms do business and are transforming the delivery of public services. Telecommunication networks are shaping the way social interactions take place, and the convergence of digital technologies is making it possible the so-called Internet of things, i.e. the increased connectedness of individuals and things on an unprecedented scale. In this extremely dynamic environment, it is crucial to understand how IP can be effectively used to stimulate and protect innovations.

ICTs are highly heterogeneous and differ in nature and characteristics; however, they share some features which are relevant when evaluating the role of patents. They are complex technologies combining several different technological components. Innovation in ICTs is a highly cumulative process, with follow-on inventions often representing improvements or re-combinations of previous products or technologies. As we will discuss in this survey, these characteristics lead to fragmentation of IP rights and to the emergence of the so-called patent thickets. In this scenario, the role of patents in stimulating innovation and technology transfer is extremely controversial.

Several actors and institutions – such as patent pools, standard setting organizations and patent intermediaries - have developed to cope with the increased technological complexity and to allow market players to "hack their way through the patent thicket" (Shapiro, 2001). However, as we document in detail, these institutions have generated a series of additional concerns. They typically require close collaboration among rival firms and for this reason they are often scrutinized by antitrust authorities. On top of this, as witnessed by the debate on FRAND licensing, members of pools and standard setting organizations may have divergent interests and goals thus making it difficult for them to reach a consensual agreement on licensing schemes. The goal of intermediaries is to increase the efficiency of the market for patent related transactions. Among the various types of intermediaries, patent assertion entities (PAEs) have raised considerable public attention. They are alleged to be one of the major responsible for the surge in patent lawsuits; born as an high-tech phenomenon, PAEs are now broadening their scope of action towards other industrial sectors such as biotech and pharmaceuticals.

A noticeable share in the increase in patenting can be ascribed to the software industry. Estimates reveal that about one third of the patents granted by the EPO and the USPTO are related to software products. Patents protecting software technologies are very controversial. As a matter of fact, the high degree of abstraction of software algorithms makes it difficult to assess their patentability and this raises concerns about the quality of the granted rights. A large share of the lawsuits in the recent "smartphone war" involved patents protecting software related technologies, a fact that is considered by many as a confirmation of the concerns regarding the low quality of software patents. Differences with the legal scope of patents for software technologies in the various jurisdictions and the heterogeneity in the examination rules at different patent offices have further contributed to the uncertainty in the field. The picture is made even more compelling due to the increasingly significant role of open source software. Based on the openness of the source code, this innovative way of creating and distributing computer programs needs to find its way to coexist with patented software.

This paper is organized as follows: in Section 2 we document the surge in patents and their changing role in ICTs, while Section 3 surveys the main theoretical contributions on the role of patenting in industries where innovation proceeds cumulatively. Section 4 presents the main problems associated with IP fragmentation and Sections 5 and 6 focus on patent pools and standard setting organizations, the traditional institutions aimed at copying with fragmentation. Section 7 discusses the literature on the market for ideas, focusing, in particular, on the role of intermediaries and PAEs. We devote Section 8 to software patents. Finally, Section 9 concludes.

2. The surge in ICT patenting

Patent applications increased steadily during the last decades. For the year 2014, WIPO (2016) estimates that the number of applications filed world-wide amounted to more than 2.4 million, a figure which is approximately three times that estimated in the 80s. About one third of these applications were filed within the ICT-related sectors. Similarly OECD (2014), looking at patents filed under the Patent Cooperation Treaty (PCT), finds that between 2009 and 2011 ICT patents were over 38% of the total. A noteworthy trend is the increase in software patenting, as we document in Section 8.

The surge in the number of patents seems to be at odds with what was found by Graham et al. (2010) in a survey on 1,332 US high-tech start-ups active in biotech, medical devices, software and IT hardware (semiconductors, communications and computer hardware). According to their evidence, for technology entrepreneurs the patent system seems neither working particularly poorly nor well for their companies and industries. Interestingly, software companies consider patents as the least important mechanism to appropriate the returns of their R&D efforts.[3] The finding that innovators very often do not perceive patents as an effective instrument to protect their innovation is well-known in the literature since the widely cited study by Cohen et al. (2000). These contrasting figures, surge in patenting and little effectiveness of patents as an appropriation mechanism, gave rise to what has been dubbed as the “patent paradox”.

This paradox can be explained by considering the changing role that patents have in modern economies and in ICTs in particular. Hoeren et al. (2015) offer an interesting historical analysis of the evolution of IP protection in semiconductors. They show that since the early stages of the industry, manufacturers relied heavily on patents; however, firms used them essentially as an effective means of sharing technologies and rarely enforced them. Today, things have changed. In semiconductors, as well as in other industrial sectors with complex technologies, patents are often used as “bargaining chips” in order to improve the outcomes of licensing/cross-licensing negotiations (Hall and Ziedonis, 2001). The literature on strategic patenting is relatively abundant. On the hand, large patent portfolios have been considered as an important defensive safeguard against the possibility of rival firms taking legal actions for patent infringement (Ziedonis, 2004). On the other hand, patents can be used aggressively against competitors. This use of patents has become very relevant and for this reason it has attracted the attention of researchers. Walsh et al. (2016) and Torrisi et al. (2016) represent two of the most recent studies conducted on this issue. Walsh et al. (2016) use a random sample of 9,060 US triadic patents observed in the period 2000-2003 and investigate the

[3] Patents are considered to be less effective than secrecy, first mover advantage, complementary assets, copyright and trademarks.

importance of preemption, that is, the use of patents to block competitors or to prevent them from inventing around. The authors find that compared to other technological areas, patents protecting computer and semiconductor technologies show high rates of preemptive use. Interestingly, they also find that the likelihood of using patents preemptively is positively associated with the strength of patent protection. A confirmation of the importance of strategic motives for patenting in ICTs is in Torrisi et al. (2016). They use survey data on inventors from 23 countries (European countries, Israel, the United States and Japan) filing applications at the EPO between 2003 and 2005. The authors show that a substantial share of patents is not being used by firms internally or for market transactions and they interpret this evidence as a support to the importance of strategic patenting. They also find significant differences across industrial sectors, with patents that are more likely to be employed strategically in complex technologies than in other areas.

One of the sectors where patenting has increased the most during the recent years is software. Bessen and Hunt (2007) argue that the rise in software patents can only partially be explained with an increase in innovation and in research and development, while it is mainly related to strategic motives. They support this view by looking at the distribution by industry of software patents granted by the USPTO. It emerges that three out of four software patents do not belong to software publishers but to firms operating in some manufacturing industries (specifically, 28% in electronics and 24% in machinery); software publishers, in principle the companies mostly involved in the development of software programs, account for only 5% of the overall number of patents. By contrast, the share of programmers and engineers, i.e. those involved in the writing of software code, is much larger in software publishers and in non-manufacturing sectors. Only 11% of the overall programmers and 32% of the total number of programmers and engineers are employed in the manufacturing sector. These figures suggest that there is little correspondence between the R&D activity aimed at developing new software and patent ownership. At the same time, companies in manufacturing industries have greater propensity to amass large patent portfolios despite employing a small fraction of programmers. This evidence, according to Bessen and Hunt (2007), represents a clear signal of strategic patenting in software.

On top of strategic uses, the empirical literature has shown that patents play also an important signaling role for start-ups and SMEs. A series of studies focus on ICTs and show that possessing a large stock of patents increases the chances of companies of being financed by venture capitalists (Cockburn and MacGarvie, 2009 and 2011) as well as it affects the amount the investment received (Mann and Sager, 2007).

3. Patents and cumulative innovation

In the theoretical literature, innovation is often described as a discrete event taking place once and for all, with no links to any past or future invention. Although useful in order to focus on the trade-off between incentives to innovate and deadweight loss and to clarify the basic role of patents, the isolated innovation approach does not capture several critical features characterizing the inventive process in high-tech industries. The cumulativeness and complexity of innovation in ICTs make the role of patents less clear-cut provided that a strengthening of the protection they guarantee may have heterogeneous effects on the different generations of innovators. More generally, in order to understand the role of patents in ICT sectors one needs to consider additional effects, beyond the traditional trade-off highlighted in the isolated innovation framework.

With a cumulative innovation process, early inventions pave the way for follow-on innovators and technology implementers. The social value of early innovations is not only related to the utility generated from their use but also to the positive externality they contribute to future applications/developments – see Scotchmer, 2004 for a thorough discussion on the cumulative nature of the innovation process. At the same time, patent protection, while increasing the R&D incentives of early innovators, may discourage follow-on inventors and technology implementers from investing. By anticipating the licensing fees due to the owners of the relevant patents, or the cost of being involved in litigation, they may choose suboptimal levels of investment or may not invest at all. This is what is known in the literature as the hold-up problem in technology innovation (Lemley and Shapiro, 2007).[4] Another potential inefficiency in the context of cumulative innovation is related to the so-called reverse hold-up, often referred to as hold-out problem. In this case, it is the follow-on inventor/implementer who, infringing on a patent, opportunistically refuses to enter into a licensing agreement with the inventor. While the empirical literature has highlighted instances where the hold-out emerges (Pentheroudakis and Baron, 2017), the theoretical contributions have mainly neglected this issue.

With cumulative innovation, also the effect of imitation on R&D incentives should be reconsidered. Bessen and Maskin (2009) observe that imitation affects firm's profitability in two ways. In the short-run, imitators compete with the innovator, thus reducing the profits of this latter. However, in the longer run, the innovator may, in turn, imitate future inventions developed by competitors, therefore providing consumers with more innovative and technologically advanced products. This second, long-run, effect increases the incentives to innovate. Bessen and Maskin (2009) believe that in highly dynamic industries such as software, personal computers and semiconductors, the long-run effect dominates the short-run one and innovation may be fostered by the possibility of imitation. Therefore, in these industries innovation would flourish in the presence of lower levels of patent protection allowing some degree of imitation.

The impact of patent rights on the overall innovation incentives and on the diffusion of the protected technologies is intimately related to the efficiency of negotiations among different generations of inventors/implementers. In one of the most influential contributions in this field, Green and Scotchmer (1995) show that the absence of failures in the bargaining over the licensing terms restores efficient incentives for the whole sequence of innovators. However, as we detail in the following sections, the literature has highlighted different reasons why negotiations may fail. Asymmetric information among contracting parties, the fragmentation of IP rights typical of ICT industries and the often alleged low quality of granted patents severely hamper the efficiency of licensing negotiations.

As regards the effects of low quality patents the contribution of Farrell and Shapiro (2008) deserves to be mentioned. They show that low-quality patents (what the authors call "weak" patents) may generate two forms of inefficiencies. On the one hand, there is a free-riding effect reducing the incentives to go to Court looking for invalidation; all follow-on innovators benefit from patent invalidation, but the cost of filing a lawsuit is borne only by the plaintiff. On the other hand, patents,

[4] It is interesting to notice that, in the theoretical literature, the terms follow-on inventors and implementers are often used interchangeably and the distiction between these two figures is rather blurred.

even the low quality ones, allow patent holders to set fees strategically in the attempt to reduce competition among implementers, thus maximizing licensing revenues.

While the theoretical literature on the effects of patents on cumulative innovation is quite abundant, the empirical evidence is relatively scant. This is not surprising given the difficulties both in measuring cumulativeness and in identifying the causal effect of patents on innovation. Galasso and Schankerman (2015) represent a notable exception. They study the impact on follow-on research of the removal of patent rights by court invalidation in the US. The authors measure follow-on innovation using later citations and solve the identification problem thanks to the fact that the US Court of Appeal for the Federal Circuit institutionally allocates judges to patent cases randomly; this allows the authors to control for the potential endogeneity of patent invalidation. According to their estimates, Galasso and Schankerman (2015) find that patents hinder follow-on innovation in computers, electronics, and medical instruments; by contrast no effects are found in drugs, chemicals, and mechanical technologies. Interestingly, they provide evidence of invalidation stimulating subsequent innovation only in relation to patents owned by large companies.

4. Fragmentation of patent rights

In ICT industrial sectors, a series of factors – the cumulativeness of the innovation process, the complexity of technologies, and the increasing patenting volumes – has "naturally" led to a high degree of fragmentation of patent rights and to the emergence of the so-called patent thickets. Often the various components essential for the functioning of a technological system are controlled by a large and dispersed number of operators; this fragmentation in property rights potentially constraints the ability to operate and forces companies to secure the necessary licenses in order "to hack their way through the patent thicket" (Shapiro, 2001). The prevalence of fragmentation/thickets in ICT-related sectors is confirmed in Hall et al., (2013) and Graevenitz et al. (2013). The authors identify thickets by counting "triples" i.e. groups of three firms in which each of them is in a mutually blocking relationship with the other two due to the patents they own. Using information on patent applications filed at the EPO, Hall et al., (2013) find a high number of thickets in all areas belonging to Electrical Engineering, especially in Telecommunications, Audiovisual Technology, and Computer Technology. Interestingly, they also find that some large ICT companies are responsible for a relevant share of thickets in other technological fields (e.g. Instruments).

For easiness of exposition, in what follows, we group the main contributions in the literature regarding the consequences of fragmentation and patent thickets into three areas.

<u>Fragmentation and royalty stacking/anticommons</u>

The economic literature suggests that patent thickets may lead to multiple marginalizations and royalty stacking (Shapiro, 2001); hence, fragmentation potentially amplifies the distortions associated with upstream monopolists. In an often cited theoretical study on biomedical research, Heller and Eisenberg (1998) warn against what they call "the tragedy of the anti-commons". With highly dispersed patent rights reading on a single technology, implementers are forced to negotiate a large number of licensing agreements and this fact may reduce their incentives to use the technology altogether. Lichtman (2006) holds a quite different view. A high degree of fragmentation implies that each patent grants control over a limited part of the technology. This fact reduces the bargaining power of patent holders who, in turn, negotiate licensing agreements less and less aggressively. The overall effect of fragmentation, according to Lichtman, is to facilitate licensing negotiations, thus favoring access to the technology. Galasso and Schankerman (2010) present a theoretical model incorporating the views both of Heller and Eisenberg as well as that of Lichtman. As fragmentation rises two contrasting effects emerge. On the one hand, the negotiation process becomes more complex provided that the number of agreements to be signed gets larger. On the other hand, however, since the value of each patent reduces with fragmentation, negotiations about each licensing agreement speed up. Whether fragmentation discourages (royalty stacking/anticommons view) or favors (Lichtman's view) technology implementation depends on which effect dominates. By using data on patent disputes in U.S. district courts, Galasso and Schankerman (2010) test their model by estimating how fragmentation affects the length of licensing negotiations. The authors find weak evidence that fragmentation accelerates the negotiation process; this moderately supports Lichtman's argument.

Patent pendency and patent quality

The surge in patenting and the associated fragmentation of IP rights have increased the backlog of patent offices. An undesirable consequence of large backlogs is that they increase the pendency periods, i.e. the time between the filing of a patent application and the granting decision by the patent office. Pendency is costly for applicants as it delays the time from which they can benefit from their innovations being fully protected; long pendency rates are costly for non-applicants too, as they increase uncertainty over the technology they can freely use (IPO, 2013).[5] Large patenting volumes may also affect the quality of patents intended as the ability of a patent to "meet the statutory patentability requirements", to "leave little doubt as to its breadth", and "to disclose information that enables a person skilled in the art to implement the protected invention" (EPO, 2012a). Under the pressure of ever increasing backlogs, examiners necessarily devote less and less time in screening applications. This issue seems to be particularly severe in the U.S.; in an influential book, Jaffe and Lerner (2004) argue that the USPTO has been issuing a significant number of low quality patents.[6] de Rassenfosse et al. (2016) evaluate the quality of patents by comparing the decisions of different PTOs regarding the protection of the same innovation. They estimate that about 2-6% of granted patents are of dubious validity, i.e. they appear to be inconsistent with the Office's own standards and, therefore, potentially invalid.[7] Interestingly, the authors find that the

[5]It deserves to be noticed that according to industry experts pendency may have the positive effect of providing patent applicants with strategic options to explore the market before the final scope of protection is fixed. This is particularly important in highly competitive fields like ICT.

[6] The issue of patent quality appears to be less relevant as regards EPO (Wild and Clover, 2015). No patent office grants patents of perfect quality as EPO opposition figures illustrate. EPO (2015) estimates that in 2014 some 4.5% of European patents were attacked by an opposition with the EPO board of appeal. Some 31% of these opposition cases led to the revocation of the patent and in another 38% of these cases the patent had to be limited in scope.

[7]More specifically, de Rassenfosse et al. (2016) distinguish two conceptually distinct reasons why low quality patents may be granted: i) Patent offices systematically apply too lenient standards for patentability; ii) the examination process is superficial so that undeserved (i.e. patents inconsistent with the patent offices' own standards) and potentially invalid patents are granted. In both cases, patent protection is not worth to be granted. In their empirical analysis, based on a sample of more than 400 thousand applications filed at different patent offices, the authors find that on top of the 2-6% patents of dubious validity, another 2-15% is estimated to be of low quality in the sense that they would not have been granted were the (stricter) standards of some other patent offices being applied.

share of patents of dubious validity is higher in frontier industries such as software and biotechnology.

Fragmentation and innovation incentives

From a theoretical perspective, the consequences of patent fragmentation on the incentives to innovate are not easy to predict, as they likely depend on firm and market characteristics. On the one hand, firms that rely heavily on the technology developed by others – mainly new entrants or SMEs – may have reduced incentives to invest in R&D as they fear to be held-up by competitors. In addition, companies may be forced to devote substantial parts of their budgets in the attempt to build large patent portfolios aimed at improving their bargaining position when negotiating cross-licensing agreements. On the other hand, fragmentation may encourage innovation of technology leaders – mainly large incumbents and companies holding sizeable patent portfolios – who can leverage the mass of patents they possess.[8] The empirical literature on patent fragmentation is relatively scarce mainly due to the lack of suitable data. Nevertheless, the available contributions confirm that the consequences of thickets are differentiated and depend on company characteristics and market specificities. Graevenitz et al. (2013) focus on the patenting behaviour of 2,074 firms filing applications at the EPO between 1978 and 2003. Their analysis confirms that for complex technologies like telecommunications, large and small firms react to patent fragmentation differently; while firms holding large portfolios patent more intensively as thicket density increases, holders of fewer patents reduce their applications in response to larger and denser thickets. Hall et al. (2013) look at how thickets influence firms' entry, defined as the decision to patent for the first time in a given technology area. They employ a sample of about 29 thousand UK SMEs observed over the period 2002-09. Using duration regression analysis, they find that the propensity to patent for the first time in a given technology area is negatively affected by thickets density; again, this evidence confirms that small firms are the ones that are eventually most harmed by thickets. Cockburn et al. (2010) find that fragmentation has a differentiated impact on companies depending on whether they need to in-license the technology they use. The authors measure firms' innovative activity in terms of the share of sales from new products. They find a negative relationship between fragmentation and their proxy for innovation in the case of firms needing to license the technology from rivals. By contrast, companies that do not in-license increase their share of sales from new products the greater the fragmentation.

5. Patent pools

Historically, the two ways that market participants have employed to cope with IP fragmentation are patent pools and standard setting organisations (SSOs). Patent pools can be defined as "an agreement between two or more patent owners to license one or more of their patents to one another or to third parties" (WIPO, 2014). Pools represent a one-stop-shop through which an implementer can access the package of patents belonging to several owners and reading on the relevant technology. Therefore, they significantly reduce the transaction costs associated with

[8] In a 2012 workshop on patents thickets, experts (practitioners, policy makers and academics) agreed that patent thickets are a consequence of technological complexity and high competition and as such are more likely to harm SMEs and individual inventors; these are less able to cope with the "cost of complexity", namely the costs associated with: the uncertainty over freedom to operate, the lack of transparency, the search of relevant prior art and legal actions (EPO, 2012b).

thickets and are seen as a potential solution to inefficiencies resulting from fragmented and overlapping patents.

Patent pools require close collaboration among member firms. As these companies are often rivals in the product market, much of the economic analysis has looked at pools from a competition policy perspective; as a matter of fact, an increasing number of antitrust cases deal with patent pooling arrangements (Gilbert, 2004). In this respect, two interrelated issues are relevant in order to evaluate the effects of patent pools. The first one, relates to the degree of substitutability or complementarity of patents forming the pool; the second one regards the possibility of independent licensing.

A well-established result in the theoretical literature is that patent pools are anti-competitive when they include patents that are perfect substitutes while they increase market efficiency in the case of perfect complements (Shapiro, 2001; Lerner and Tirole, 2004). When patents are perfect substitutes, the pool eliminates competition on royalties among holders of patents addressing exactly the same functionalities; therefore, in this case, the members of the pool benefit from reduced competition to the detriment of market efficiency, as in a standard cartel. By contrast, when technologies are perfect complements, pools are pro-competitive as members internalize that larger royalties reduce the demand for complementary patents and, consequently, they are induced to lower licensing fees. In other words, with perfect complements, patent pools mitigate royalty stacking.

Lerner and Tirole (2008) highlight that these arguments apply neatly but only in the extreme cases of perfect substitutes/complements. In the intermediate cases of imperfect complementarity or substitutability of patents, the consequences of pools are more nuanced. The authors show that the desirability of patent pools depends on a series of conditions such as the ability of prospective licensors to invent around, their capacity to invalidate patents or the possibility of pool members to grant individual licenses. The role of individual licensing on pools efficiency has been investigated more in detail in Lerner and Tirole (2004). The two authors show when the pool is aimed at increasing royalties (as in the case of substitutes patents) independent licensing restores competition among pool members and therefore it is welfare enhancing; on the opposite, with complementary patents, competition in royalties does not produce any effect. Lerner and Tirole's arguments support the approach followed by competition authorities that often impose independent licensing to pool members; the authors, in fact, suggest that independent licensing reduces profitability of "bad" pools, i.e. pools aimed at increasing royalties.

Another issue that has been extensively studied in the literature regards the effects of the so-called grant-back clauses. A grant-back clause requires pool members to disclose and transfer all improvements made in the licensed technology for free or at a low price. Such a requirement generates a trade-off between lower incentives to innovate and lower risk of hold-up. With grant back clauses, firms may be discouraged from innovating as they anticipate lower returns from the licensing of future patents. However, grant-back clauses protect from members' opportunism; for example, they prevent companies from hiding essential innovations in an attempt to hold-up other members once the pool has formed (Lerner and Tirole, 2008).

The empirical evidence on the effects of patent pools on firms' innovative activities in ICTs is mixed. Joshi and Nerkar (2011) analyze data on innovation in the global optical disc industry and find that patent pools have significantly decreased both the quantity and the quality of patents obtained by pool members. Based on this evidence, the authors suggest that pools seem actually to inhibit, rather than stimulate, innovation. Vakili (2012) investigates the impact of the MPEG-2 pool focusing on the innovation rate of outsider firms that are technologically proximate to the pool. Also this study finds a negative effect of the pool, with outsider firms innovating less after the pool formation. However, by looking at the underlying mechanisms driving this result, Vakili (2012) shows that the observed reduction in innovation rates is mainly due to a shift in firms' strategy: investments in technological exploration seems to have been replaced by greater efforts in implementing the MPEG-2 technology in their own products. These negative effects of pools on innovation incentives are questioned by Baron and Pohlmann (2015). According to the two authors, in order to better understand the consequences for innovation one should also take into account the dynamics of patenting before the actual formation of the pool. More specifically, Baron and Pohlmann (2015) collect information on 50 patent pools in ICT industries; some of these pools were announced but then failed to take-off while others were also actually implemented. The authors find a significant increase in patenting just after the announcement of the pool; the effect is stronger for pools that were not only announced but that, later on, were also actually formed. Prospective members of the pool contributed the most to the increase in patenting in this pre-formation period. Based on these findings, the authors suggest that the decline in innovation activities found in previous articles on patent pools should be interpreted cautiously, as one should also look at the dynamics just before the advent of the pool.

6. Standard setting organizations and FRAND licensing

Together with pools, Standard Setting Organizations (SSOs) are the other traditional institutional arrangement useful to cope with the inefficiencies related to fragmentation. Standards are ubiquitous in ICT industries due to the strong need for interoperability. Typically, SSOs are formed by industry stakeholders who endorse a particular technology and promote its adoption among market participants (Simcoe, 2011). Standards aim at facilitating the deployment of new technologies on the largest possible scale and create a level playing field for competition in related product markets. Standardized technologies include a large number of patented inventions; the prospect of licensing patents that are essential to standards – the so-called standard-essential patents (SEPs) – on an industry-wide scale is a major incentive for companies to invest in standardization activities. Most SSOs have defined intellectual property rights policies whereby members commit to licensing their SEPs on "fair, reasonable and non-discriminatory" (FRAND) terms (Meniere, 2015).

<u>The debate on FRAND licensing</u>

As discussed in Meniere (2015), until the 1990s, when SSOs started adopting FRAND policies, licensing negotiations took place among few companies with quite aligned interests, all involved both in the development and in the implementation of the standard. These vertically integrated companies typically ended-up cross-licensing their SEPs, thus paying little royalties to each other. By contrast, today the rapid evolution of information and communication technologies, coupled with the need for wider and deeper interconnectivity, has led to a variety of SEP owners and implementers with different business models and to a greater diversity of licensing practices. As a result, it has become more difficult to identify a consensual interpretation of FRAND licensing principles. It is often argued that FRAND commitments are too loose to effectively prevent SEP owners from unduly leveraging market power once the standard is implemented ("hold-up" argument). Others argue that FRAND commitments enable technology implementers to deliberately avoid seeking licenses for SEPs ("hold-out" argument). Moreover, the fragmentation of SEP ownership might lead to an excessively high royalty stack ("royalty stacking" argument) (Baron et al., 2016a).

The theoretical literature on FRAND licensing has mainly focused on the hold-up problem and on the exact meaning of "reasonable" royalty rates. The basic argument suggesting the risk of hold-up is quite simple and rests on the idea that, once a standard is defined, the industry is "locked-in" and SEP owners gain monopolistic positions; as a matter of fact, before the standard is defined several technologies compete to be included in the standard while, once the standard has been developed and adopted, implementers are forced to use the, by then essential, technologies. The distinction between the ex-ante and the ex-post values of the technologies is at the heart of Swanson and Baumol's (2005) influential paper. The two authors suggest that a SEP should be remunerated according to its "incremental value", that is the valuation that would emerge in an auction or other forms of bargaining among substitute technologies prior (ex-ante) to the definition of the standard. Though theoretically elegant, this proposal faces some practical problems; first of all, the royalty rates are actually set ex-post, when the standard is at the commercialization stage. If this is the case, it might be difficult to have a full understanding of the competing technologies that were available at the time of the definition of the standard. For this reason an SSO's best practice would be to keep track of the ex-ante feasible technologies in order to inform subsequent negotiators and arbitrators of the technical alternatives (Lemley and Shapiro, 2013). Another difficulty in implementing the incremental value criterion rests on the fact that typical licensing negotiations involve several SEPs and this makes the determination of the value of each patent an extremely complicated matter (Gupta, 2013). An even more serious shortcoming of the incremental value criterion is highlighted in Layne-Farrar and Llobet (2014); when, ex-ante, the difference between competing technologies is one-dimensional (e.g. they are identical but differ only in production costs), the incremental value can be determined rather easily. However, as technologies are of interest of many users with different needs and preferences, there is not a unique incremental value which, instead, is user-specific.

One issue that has attracted the attention of researchers regards the practical implementation of FRAND licensing. Typically, FRAND provisions do not impose specific obligations for the determination of SEPs licensing terms; rather, they define a general framework and leave the identification of the exact conditions to negotiations between patent holders and implementers. If, on the one side, this flexibility allows parties to tailor the agreements to their specificities, on the other side it comes at the cost of a lack of transparency and of a larger degree of uncertainty (Meniere, 2015). Practitioners and industry experts argue in favor of this flexibility, but they also recognize that some limitations might help in reducing uncertainty and the associated transaction costs. Meniere (2015) lists a set of possible interventions, including the disclosure of information on SEP licensing conditions; knowing the terms of previous agreements may help current negotiators in defining a benchmark for the determination of reasonable rates.

Moving from the observation that FRAND commitments are ambiguous, Lerner and Tirole (2015) build a theoretical framework that highlights the main trade-offs arising in the determination of the licensing terms of standard essential patents. They suggest to impose patent holders a commitment to a maximum royalty before the definition of the standard. In a manner which is reminiscent of

Swanson and Baumol (2005) arguments, ex-ante competition in royalty caps among technologies willing to be included in the standard would be a way to restore efficiency. In principle, the commitment to royalty caps proposed by Lerner and Tirole (2015) would made FRAND provisions redundant; nonetheless, the inability of SSOs to identify all the relevant technologies limits the efficacy of royalty caps and calls for the adoption of FRAND commitments anyway. In the view of the authors, therefore, royalty caps and FRAND commitments would complement each other.

A different issue that has attracted the attention of the economic literature on SSOs regards the quality of SEPs; the discussion has been fuelled by the recent "smartphone war" – discussed later in the survey – which is seen by many as caused by the presence of essential patents of low quality. Regibeau et al. (2016) suggest to impose a significant declaration fee for SEPs and regular essentiality tests of a random sample of SEPs. Testing essentiality of SEPs would raise their quality and could considerably contribute to reduce transaction costs. It is not clear, however, who should carry out these tests, what the costs would be and who would bear them. Analyzing the case of ETSI, the European Telecommunications standards Institute, Pohlmann and Blind (2016) suggest that SEPs tests might be carried out by the European Patent Office. Rysman and Simcoe (2008) provide different evidence on the quality of SEPs. They use information collected from the publicly available IPR disclosure archives of four major SSOs (ANSI, IEEE, IETF and the ITU) between 1971 and 2006, and find that, prior to disclosure, patents reading on standards receive roughly double the citation rate of an average patent. They interpret this finding as evidence of a high quality of SEPs, with SSOs performing well in selecting technologies with higher inherent merit.

The role of courts in FRAND licensing

A related matter of contention regards the role of courts in case licensing negotiations fail. In the US, courts play an active role in the determination of the licensing terms; reasonable royalties are determined on the basis of a "hypothetical" negotiation that would have taken place between the parties before the infringement. As stressed in Pentheroudakis and Baron (2017), US courts are methodologically sophisticated,[9] even though their approach based on a hypothetical negotiation appears to be quite difficult to be implemented in practice. European courts are, instead, more focused on the conduct of parties during negotiations and they specifically assess whether patent holders have complied with the obligations imposed by FRAND commitments. Some differences between the two sides of the Atlantic emerge also in relation to the imposition of injunctions. Traditionally, US courts have been reluctant to grant injunctive reliefs to SEP owners committed to FRAND licensing. In contrast, European courts tended to be more prone to concede injunctions; things have changed since the 2015 decision of the Court of Justice of the European Union in Huawei *vs* ZTE (Baron et al., 2016b). The ruling restrains the possibility of seeking injunctive relief by specifying a set of requirements that must be fulfilled by the SEP owner. Specifically, before seeking

[9]In a landmark decision in 1970 - Georgia-Pacific Corp. *vs* United States Plywood Corp - Judge Tenney established 15 factors to be considered for the determination of reasonable royalties; these are known as the Georgia Pacific factors. The pioneer case for FRAND in the U.S. is Microsoft Corp. *v*s Motorola, Inc. in 2012. The court established that royalty rates should be determined as the outcome of a hypothetical bilateral negotiation ex ante to standard setting.

an injunction the patent holder must inform the implementer about the infringement and must present a detailed offer indicating the royalty rate and the way in which it has been determined.

SSOs and innovation

The literature has devoted far less attention to the relationship between SSOs membership and firms innovative activities. As suggested by Baron et al. (2014), despite the fact that SSOs are intended as an institution to speed up the standardization process and, as such, to improve market efficiency, they may have undesired effects on the incentives to innovate of their members. Often companies contributing to the standard adhere to informal consortia to supplement the formal standard setting process; the three authors study how these consortia can help coordinating R&D efforts thus mitigating market failures. Using information on a large panel of ICT standards issued between 1992 and 2009, they find that firms tend to innovate more after joining the consortium. However, this effect disappears, or it is even reversed, when the firms R&D incentives are mainly driven by the prospect of licensing a standard essential patent. Blind et al. (2017) study the interplay of standards and governmental regulation on firms' innovative efficiency, measured in terms of the resources needed to innovate. The authors use information collected within the 2011 German Community Innovation Survey and find that regulation and standards have opposing effects which depend on the degree of uncertainty characterizing the environment within which companies operate. They distinguish markets with low or high degree of uncertainty on the basis of an index combining different sources of uncertainty (competition, consumer behavior, technological complexity). The authors find that, in the case of low market uncertainty, standards reduce innovation efficiency while regulation increases it; with high market uncertainty, results are reversed.

7. The market for ideas

One of the crucial roles of patents is to favour the market for ideas, that is a place where the right to use a technology is traded, either via licensing or via outright sale. As already mentioned (see Section 3), Green and Scotchmer (1995) show that an efficient patent market guarantees the correct R&D incentives for the whole sequence of innovators. It is difficult to estimate accurately the overall magnitude of the market for ideas as most transactions are confidential. Nevertheless, available evidence suggests that it has grown considerably during the last years (see Arora and Gambardella, 2010 for a survey). Recent figures reveal that cross-country licensing for patents, trademarks and copyright, including transactions among affiliated entities, increased in the OECD area by an average annual rate of 10.6% between 2000 and 2010 (OECD, 2012). Athreye and Yang (2011), updating a previous work by Athreye and Cantwell (2007), show that overall license and royalty payments reached approximately USD 180 billion in 2009. In a survey with a sample of more than 2,000 European and Japanese firms, Zuniga and Guellec (2008) find that about a fifth of European companies and a fourth of the Japanese ones license patents to non-affiliated firms. The two authors also observe that, between 2003 and 2006, licensing has increased in importance for about 45% of the firms in the sample. Akcigit et al. (2015) measure the extent of the patent market by focusing on outright sales. They estimate firm-by-firm transfers using information from the NBER-USPTO patent grant database and from the patent reassignment data hosted in Google Patents Beta. They find that, among the patents registered at the USPTO during the period 1976-2006, 16% were traded; this number goes up to 20% among domestic patents. Looking at the sectorial level, ICT firms appear to be involved in technology licensing much more than companies in other sectors (Sheehan et al., 2004). Interestingly, according to Hagiu et al. (2011) individual inventors and SMEs seem to be the least able to access patent markets. By combining information taken from several different public sources, the authors find that, indeed, in the United States, large companies contribute about to 40% of all patents but obtain 99% of the revenues generated through licensing. Therefore, it seems that market distortions reduce the ability of small firms and inventors to monetize the value of their patents.

Despite the impressive growth registered during the recent years, the market for ideas appears to be prone to failures. Drawing from the literature on market design, Gans and Stern (2010) identify several potential inefficiencies characterizing the patent market. First of all, patents are inherently difficult to evaluate; parties may have disparate expectations about their value and little information can be drawn from previous market transactions. Moreover, with highly fragmented IP rights, as in ICTs, the acquisition of a single patent is of little value, unless prospective buyers already own complementary patents. These complementarity/portfolio effects reduce the number of potential buyers, thus making the market less "thick". In addition to that, the cost of searching and identifying potential buyers or sellers of the technology is substantial; this is all the more so as the number of patents reading on the relevant technologies/products gets larger. Finally, negotiations take place in the shadow of litigation and licensing terms heavily depend on the opportunity cost of going to trial for the involved parties rather than on the actual value of the patent. As a consequence of these inefficiencies, it is frequently mentioned that potentially valuable patents might not be commercialized and fully exploited for innovation (Giuri et al., 2015).

Moving from these considerations, Agrawal et al. (2015) employ licensing data from the 2006 survey conducted by the Licensing Foundation in the US and Canada to estimate the main reasons of deal failures in the market for ideas. They identify three stages in the licensing process, the initial stage of identification of the prospective buyers/sellers, the intermediate stage where negotiations occur and the last stage where the agreement is reached. The authors find that significant failures occur especially in the first stage where the lack of market thickness prevents identifying potential buyers/sellers, and in the last stage because of the classical Arrow's appropriability problem which makes sellers hesitating in providing full information about the technology (Arrow, 1962).

Frictions at the initial stages of the licensing process associated with large search costs and pervasive information asymmetries are found to play a major role also in Gambardella et al. (2007).[10] The lack of transparency regarding patent transactions has been recognized by industry experts and analysts as one of the major impediments to the development of the market for ideas. As a matter of fact, when intellectual property changes hands, there is often no record of the transaction; this generates uncertainty over who is in the market, what their intentions are, and whether their property rights are already licensed. This lack of transparency leads potentially to more infringements, higher transaction costs, and larger expenses for dispute resolution (Giuri et al., 2015). This issue is so relevant that the USPTO has recently made available on Google Patents information on reassignments; these data inform about changes in patent ownership since the year 1980 (see

[10] Comino et al. (2011) develop a game-theoretic model to show that even in the presence of a "weak" form of asymmetric information - the inability of the early inventor to observe the timing of the investment of the follow-on inventor – innovators are prevented from negotiating efficiently.

Akcigit et al., 2015). The market itself is coming up with new models, like the recently initiated Avanci.com platform for the licensing of wireless technologies, aimed at allowing developers and implementers to disentangle what technology rights they need and how to get them. It will be interesting from a research perspective to analyze how these new business models will impact on patent markets in the future.

Patent intermediaries

In principle, intermediaries may play a crucial role in curbing the inefficiencies characterizing patent markets. However, Hagiu and Yoffie (2013) argue that "traditional intermediaries" such as brokers, patent pools and standard setting organizations play a limited role in mitigating market distortions. Brokers facilitate the sale or the licensing of patents but tend to focus on high-end transactions only. Patent pools, instead, emerge under very specific conditions. They arise in the presence of multiple marginalizations/royalty stacking problems, substantially limiting the scope for technology licensing. Also more recent forms of intermediaries (patent auctions and "ebay-like" online patent marketplaces) are unlikely to represent a real fix to inefficiencies either because they fail to increase market thickness or because they are inherently unable to address the classical Arrow's appropriability problem.

According to Hagiu and Yoffie (2013), a more promising type of intermediaries are patent aggregators. The two authors distinguish between defensive aggregators and super-aggregators. Defensive aggregators offer their clients a sort of "insurance" against the risk of been sued for infringement. More specifically, defensive aggregators identify and purchase patents that might threaten their clients (who, in turn, pay annual subscription fees to the aggregator or contribute directly to the purchase). These patents are then licensed by the aggregator to its clients for use in legal suits. Super-aggregators act both defensively, by licensing the acquired patents to their clients/investors, and also aggressively by suing third parties in search for licensing revenues. In this latter respect, super-aggregators are considered as a form of patent assertion entity which we will discuss below. Probably, the most well-known super-aggregator is Intellectual Ventures which, by holding approximately 40,000 patents concentrated in ICT sectors, represents one of the largest patent portfolios world-wide. Intellectual Ventures has raised large investments from prominent technology companies such as Amazon, Apple, eBay, Google, Intel, Microsoft, Sony, Samsung, etc..

Patent assertion entities (PAEs)

Patent assertion entities (PAEs) represent one of the most controversial phenomena related to the market for ideas. PAEs are generally referred to as entities acquiring patents from third parties and exploiting them in order to maximize earnings from licensing and litigation (see Schwartz and Kesan, 2014 and Cohen et al., 2014). Typically, PAEs do not rely on manufacturing or selling products; sometimes, they offer their clients ancillary services such as IP consulting or assistance for the development of patent portfolios. One of the reasons why PAEs are so controversial is that they are considered to be one of the major responsible for the surge in patent litigation. For instance, Chien (2013) estimates that, in the year 2012, nearly two-thirds of patent lawsuits in the US were initiated by a PAE (about 2,900 out of 4,700 of the cases), with a marked increase with respect to the previous years. In Europe, PAEs appear to be a less pervasive phenomenon; according to Love et al. (2017), in the UK (years 2000-13) and in Germany (years 2000-08) patent assertion entities were responsible for about 10% of the patent lawsuits. As a matter of fact, the legal fragmentation of patent protection under the existing European patent system disincentivizes PAEs from carrying out assertion activity on a pan-European scale. On top of this, the “loser pays” rule adopted in the EU legislations for the allotment of legal expenses further discourages PAEs from initiating legal disputes.

The increased importance of PAEs has stimulated an intense debate concerning the potential impact of their activities. On the one hand, PAEs are supposed to increase market thickness thus improving efficiency. They are also expected to mitigate the so-called “hold-out problem” i.e. the opportunistic behavior of large companies that consciously infringe SMEs IPRs without paying any licensing fees. In this view, small innovative companies may rely on PAEs as a counter-balancing instrument against powerful infringers (Chien, 2013 and Pohlmann and Opitz, 2013). On the other hand, opponents of PAEs argue that these companies exploit the imperfections of the legal system and the main consequence of their activities is to raise the cost of innovation.

Two recent reports by the Federal Trade Commission and the Joint Research Center of the European Commission provide an overview of PAEs activities in the US and in Europe, respectively (FTC, 2016 and JRC, 2016). PAEs appear to be a very heterogeneous phenomenon with respect to several dimensions such as funding, strategies, and services offered to their clients. FTC (2016) distinguishes between “Portfolio” and “Litigation” PAEs depending on their business model. The former tend to be strongly capitalized and to purchase patents outright. They negotiate high-stake licensing deals (worth in the millions of dollars) covering large patent portfolios. Litigation PAEs, instead, typically sue potential licensees looking for a quick settlement afterwards. The FTC study reveals that despite being the predominant form of patent assertion entity (they account for 96% of the examined cases), Litigation PAEs generate only 20% of the reported licensing revenues. Interestingly, the licenses negotiated by Litigation PAEs seem not to reflect the actual value of the patents; on average each deal amounts to less than $300,000, a figure which closely approximates the lower bound of litigation costs (FTC, 2016). This corroborates the hypothesis of this form of PAEs being mainly involved into nuisance litigation. ICT sectors are the most impacted by both in Europe and in the US, though recent evidence reveals that PAEs are now moving in other sectors, such as pharmaceutical and biotech (Feldman and Nicholson Price, 2013). According to FTC (2016), nearly nine out of ten of the patents controlled by PAEs are high-tech. In Europe, PAEs acquired the vast majority of their patents from large handset manufacturers: the development of new technologies/products, such as smartphones, put incumbent manufacturers under pressure and, as a reaction to their declining businesses, they started selling their patent portfolios to PAEs (JRC, 2016). Not surprisingly, ICT industries are the most affected also in terms of asserted patents (on this point, see also Haus and Juranek, 2014 and Helmers et al., 2014); for instance, in Europe, alleged infringements frequently involve standard essential patents. Both the FTC and JRC reports cannot confirm a large scale impact of PAEs’ activity on consumers; overall their welfare effect is mainly determined by the quality of the asserted patents (JRC, 2016). Patents of generally higher quality in Europe are one reason for the lower amount of PAEs activity and less litigation in Europe compared to the US. A radically new legal framework is expected to be introduced in Europe with the implementation of the unitary patent system and the unified patent court (IPO, 2014). Under the new legislation, a unitary patent granted by the EPO, will provide uniform protection all across Europe. The unified patent court, in turn, will be responsible for rulings in disputes regarding unitary patents. It is unclear at this moment as to how far the upcoming regime will provide more or less business opportunities for PAEs. It is recognized that the alleged advantages of the new European system – e.g. the reduction in patenting costs – may favour PAEs’ activities; however, much will depend on the continuation of

delivery of high quality patents and the establishment of a new high quality court system (JRC, 2016).
An interesting evidence which may help shedding light on PAEs controversial role is in Cohen et al. (2014). The authors present a large-sample study based on the complete universe of PAEs litigation activity in the United States between 2000 and 2015; they find evidence that large assertion entities tend to behave opportunistically as they mainly sue firms that have substantial cash holdings. On the contrary, for small PAEs the cash holdings of the target firm are not a significant factor. The prevalence of opportunistic motives is confirmed by the fact that PAEs frequently forum shop (i.e. they look for the most favorable jurisdiction where to file the lawsuit) and that they tend to target firms against which they expect to have greater chances of winning the trial (the target firms are often involved in other litigation cases or have small legal teams). On similar lines, Hagiu and Yoffie (2013) observe that PAEs tend to sue target-companies at times when they are most vulnerable, "like just before the release of a new product, when the target can ill afford a risky trial". Furthermore, by not being active in production, PAEs have the advantage that they do not risk to be counter-suited (de Bisthoven, 2013).
An intensively debated issue regards the impact of PAEs on firms' innovation and on technology diffusion. As highlighted in FTC (2016) and in JRC (2016), PAEs activity typically does not involve any technological transfer provided that patent license or litigation usually occur after the product at issue has already been developed or commercialized. This "ex-post" nature of PAEs transactions has raised concerns about their impact on innovation and economic growth (FTC, 2016 and JRC, 2016). A different perspective is taken in Cohen et al. (2014); the authors look at the impact of litigation against PAEs on the innovation activity of targeted firms. They find that losing against PAEs (either in Court or via a private settlement) significantly reduces firms' R&D activities; compared to the behavior of similar companies not involved in litigations, the reduction is estimated to be around 20%. Clearly, as the authors observe, for an overall evaluation of the consequences of PAEs litigation on innovation one should also consider that often assertion entities help small inventors to respond to infringement actions by large firms. In this case, a fraction of the damages obtained by patent assertion entities may go back to the initial inventors thus increasing their earnings from innovation. However, the available estimates indicate that initial inventors obtain only a minor part of the damages cashed by PAEs (Bessen et al., 2012 and Bessen and Meurer, 2013). Bessen et al. (2012) estimate a very low pass-through: only five cents of every dollar in damages paid to a PAE goes to the benefit of the initial inventor. An interesting analysis is conducted by Kiebzak et al. (2016). The authors study the relationship between patent litigation and venture capital investment, a primary source of funding for entrepreneurial activity. They find interesting differences depending on whether litigation is brought by "frequent" litigators (a proxy for PAEs) or "regular" ones. Litigation initiated by PAEs has an unambiguously negative effect on venture capital funding while for regular patent litigators the authors find an inverted U-shaped relationship.

8. Patents for software

If the patent system raises several controversies, this is even the more so in the case of software, probably the most important ICT segment. Computer algorithms are protected by copyright and originally they were not a patentable subject matter. In the early days of the computer industry, companies did not consider software as a product per se but they used to distribute it bundled with hardware. Since the late 70s, with the advent of personal computers, software development was gradually separated from hardware production and companies, especially in the US, put growing pressure to consider software a patentable subject matter. After a series of courts decisions, in the US the patentability of computer programs has broadened; since the mid '90s software related-inventions (often referred to as computer implemented inventions, CIIs) are treated as no different to inventions in any other technological field.[11] This pro-software patent regime has led to an exponential growth in the number of patents granted by the USPTO. Nonetheless, some recent rulings are changing the scene and today, in the US, it is more difficult to obtain patent protection for software applications.[12] In Europe, the EPC (European Patent Convention) excludes computer program claimed "as-such" from patentability. A computer program to be patentable needs to produce the so-called "technical effect", that is solving a technical problem in a novel and non-obvious manner (EPO, 2014). The European legal framework appears to be quite stable, without significant changes over the last years; at the same time, the recent rulings in the US have made the two approaches to software patentability more similar and today it cannot be concluded which one of the two systems is more open towards software patent eligibility (Strowel and Utku, 2016).

The controversies about the role of patents in computer programming are related to the peculiar characteristics of software creation and distribution. Very often developers literally re-use lines of code from previous packages in order to create new applications; patent rights may potentially interfere with this common practice thus inhibiting innovation. This issue is even more relevant in relation to open source software where innovation is inherently based on open/free access to software code.

A second important feature of software relates to the high level of abstraction characterizing the underlying technology (Bessen and Meurer, 2008). Software algorithms can be represented in several different ways; at the same time, two apparently different algorithms may turn out to be equivalent. Bessen and Meurer (2008) discuss the example of the "traveling-salesman" algorithm for routing delivery trucks; some time after its development, this algorithm was found to be equivalent to another one used to solve the map-colouring problem, a quite different purpose in practice. Abstraction of software technology makes it extremely difficult to know whether a given invention is truly different from previous ones. In this context, patent protection may be problematic as it might be difficult to ascertain whether a new software program is actually novel and non-obvious.

Patents in software: some empirical evidence

Estimating the actual number of software patents is a complex matter. Computer implemented inventions are embedded into technological systems potentially belonging to any industrial area;

[11]In the 1981 decision Diamond *vs* Diehr, the US Supreme Court established that an invention embedding a computer program could be patented. Software has been considered as any other invention since 1994 when the Court of Appeals for the Federal Circuit ruled that software running on general purpose computers is patentable (in re Alappat case).

[12]In 2008, a landmark decision of the Court of Appeals for the Federal Circuit has established new guidelines for patent-eligibility (the Bilsky case). This decision has made it more difficult to obtain protection for some forms of applications, particularly those where computer implementation would be generally irrelevant, or at most incidental. More recently, in 2014, the US Supreme Court declared that a software package for facilitating financial transactions was ineligible for patent protection (Alice Corp. *vs* CLS Bank International case). This decision has increased uncertainty about the patentability of computer programs in the US to the extent that for some judges a broad interpretation of the decision might represent the death knell of software patents (see Zivojnovic, 2015).

therefore, in order to assess the magnitude of software patenting, researchers usually resort to keywords searches in the application documents. One of the first attempts to estimate the extent of software patenting is in Bessen and Hunt (2007). Using information on the patents granted by the USPTO, they find that the share of software patents spectacularly increased from 1.1% in 1976 to 14.9% in 2002. Poo-Caamaño and German (2015) extend the study by Bessen and Hunt to more recent data and estimate that the share of software patents granted in the US soared to a noticeable 36.4% in 2014.

As regards Europe, Frietsch et al. (2015) look at patent applications filed at the EPO from 2000 to 2010. By running keywords searches in the title, abstract and claims of each filing, the authors estimate that since 2002, more than 35% of all applications at the EPO are CIIs. They find that the majority of software filings are applied for by US and Japanese companies, followed by companies from Germany, France and Korea. Looking at the number of filings by industrial area, the authors notice that computer program filings are not limited to the software industry; about 78% of applications in Europe are filed within the manufacturing sectors, particularly in "Manufacture of computer, electronic and optical products", followed by "Machinery and equipment" and "Electrical equipments". This is a further evidence that computer program patents play a major role outside the software industry.[13] Frietsch et al. (2015) also observe that, in Europe, the share of patents applied for by SMEs is smaller in software than in other industrial sectors. However, the authors show that the share of software patents belonging to SMEs is larger in Europe than in the United States. This latter finding is in line with previous evidence and shows that in the US the patenting activity in the software industry is concentrated in the hands of large companies (Bessen, 2012).

The growth in software patenting has attracted the attention of several scholars. An interesting stream of research has investigated the value of software patents. Hall and MacGarvie (2010) employ an unbalanced panel of more than one thousand publicly traded US firms to estimate the private value of CII patents; their analysis covers a very broad period (from 1975 to 2002) and this allows the authors to control for the effects of the expansion of software patentability following different important Court decisions. They find evidence that rulings broadening software patentability had an immediate and negative, although moderate, impact on the stock market values of software producers; this effect was especially concentrated in firms with little experience in patenting. In a longer-run perspective, Hall and MacGarvie (2010) find that market value of firms holding large stocks of patents is higher than that of companies without software patents. However, marginal applications (i.e. applications not contributing significantly to the total stock of citations received by a company) seem not to impact on market value. Noel and Schankerman (2013) present a similar analysis; they look at the impact of strategic patents in software on firms' market value. Patents are found to be valuable for firms as they generate large premiums in stock market performance. At the same time, Noel and Schankerman (2013) show that fragmentation increases R&D and patenting by firms but it lowers their market value.

Software patents quality

[13] Rentocchini (2011) obtains similar results in terms of nationality (mostly American and Japanese firms) and sectors to which the applicants belong to (mostly sectors different from software publishing). He also provides evidence that software firms do not consider patents an effective appropriability mechanism; rather patents are mainly filed for strategic motives.

One of the main concerns with patents in ICT in general and with software patents in particular is the quality of granted rights. A decline in patent quality increases transaction and litigation costs, thus endangering the functioning of the patent system as a whole. A series of studies has been conducted in the US; with few exceptions (Allison and Mann, 2007 and Graham and Vishnubhakat, 2013) there is a general consensus regarding a lower quality of software patents compared to non-software ones. Miller (2012) measures quality by looking at the validity of patent claims. The author collects information on patent lawsuits filed in the US from 2000 to 2006 and shows that software and business methods patents, which are typically software patents as well, are more likely to have invalid claims.[14] On similar lines, in a more recent paper, Miller (2014) shows that in the period 2002-2012, the Court of Appeals for the Federal Circuit has reversed the decision of the District Court judges on software patents much more frequently than for other patents, 40% compared to 24% of the times (similar findings are in Bessen and Meurer, 2008).

Miller and Tabarrok (2014) argue that the lower quality of software patents is due to a too broad application of the so-called "means-plus function" claiming; the US patent law allows claims specifying the final purpose of an invention (functional claims) provided that they are limited by a specific means. When applied to computer programs, functional claiming has been too loosely applied ending-up in specifying very generic means such as "a computer" or a "data processing system". This interpretation of US courts imposes very little limits to functional claims in software patents. Bessen (2014) supports the view that the low quality of software patents is related to the high level of abstraction of computer programs which, as discussed above, makes it more difficult for examiners to ascertain whether a technology is truly different from existing ones. According to Bessen, in the presence of abstract technologies it is almost inevitable for patent offices to issue patents with invalid claims or with ill-defined or "fuzzy" boundaries regarding the scope of protection. In addition to these arguments, Cockburn and MacGarvie (2009) observe that the lack of experience of US examiners in the new subject matters, such as software, has reduced their ability of searching the prior art, thus increasing uncertainty about the validity of granted patents.

Smartphone wars

Since 2007, the largest manufacturers of smartphones and other electronic devices started suing and counter-suing each other, claiming infringements of several patents and designs. The amount of legal actions reached unprecedented levels; in less than seven years, the top ten producers totalized more than 1,100 patent lawsuits worldwide (Yang, 2014). This wave of lawsuits, which has significantly influenced the competitive landscape of the smartphone market, is known as the "smartphone war" and it represents a clear example of the possible consequences of the strategic use of patents that we have documented in Section 2. It is widely believed that the root cause of this surge in litigation lies in the poor quality of software patents. This view is not shared by everybody, though; this is the case of Graham and Vishnubhakat (2013). The two authors focus on a series of high-profile lawsuits involving four of the major industry players, namely Apple, Microsoft, Motorola and Samsung. They find that 65 of the 73 asserted patents contained at least one software-related claim. Of the 21 software patents that, at the time their paper was drafted, had already been examined by some US federal district Courts, only 4 were found to be invalid or likely invalid.

[14] These stances are confirmed in GAO (2013) that finds that in the period 2007-2011 nearly half of the US patent lawsuits were software-related.

According to Graham and Vishnubhakat, the fact that about 80% of the asserted software patents (17 out of 21) were, instead, declared valid (or likely to be so) by Courts is a clear evidence of their quality.

These arguments have been criticized in Miller and Tabarrok (2014). First of all, they argue that 4 out of 21 is far from being an acceptable proportion of invalid patents. This is even the more so if one considers that the ones being asserted are likely to be of higher quality than the average software patents; as a matter of fact, in smartphone wars litigants are large and established ICT practicing companies which are likely to hold valuable patents and litigate only when benefits are expected to be larger than costs.

Teece et al. (2014) hold a more nuanced view. They do not deny the role of low quality patents in spurring litigation. However, they see smartphone wars being a corollary of the technological complexity characterizing ICTs; higher patent litigation reflects the high degree of competition and the large business opportunities in the market. Moreover, Teece et al. (2014) argue that patent wars can also be attributed to the not self-enforcing nature of IP rights. As a matter of fact, competitors can use protected technologies without permission and therefore for patentees litigation (or the threat of litigation) is the only way to enforce their rights.

Software patents and Open Source Software

In the recent years, open source software (OSS) has made inroads into several segments of the industry thus proving to be an extremely dynamic and innovative way of creating and distributing computer programs. In contrast with proprietary software, in OSS the source code is made available for using, reading, changing it or developing further versions of the program. The aim of these provisions, generally referred to as “copyleft”, is to keep the software source code open, thus promoting access, diffusion and collaborative development of programs.

The surge in patenting has raised concerns on the coexistence between OSS and proprietary software; more specifically, software patents may clash with the distributed and incremental approach to innovation typical of OSS. Since the well-known SCO-Linux controversy in 2003, a series of legal disputes have been involving OSS developers and users; for example, in 2011, Lodsys LLC, a very active PAE in the software market, sent letters to a number of small open source mobile application developers claiming that they were infringing on its patents. For this reason the OSS community started adopting defensive strategies against unwarranted assertion of patents (for details, see Burns, 2013). One of such strategies is the creation of defensive patent pools. The most prominent example is Open Invention Network (OIN) which was launched in 2005 with the mission to protect Linux. This defensive patent pool is backed by some major ICT players such as Google, IBM, Philips, Red Hat, Sony, NEC, Novel and dozens of other large and small organizations. OIN owns around three hundred patents which are made available free of charge to any company or individual that agrees not to assert its patent against the Linux system (see Burns, 2013).

The literature has highlighted that litigation, or the threat of possible litigation, may have important consequences for OSS. Specifically, Wen et al. (2013) examine the impact of patent enforcement targeting OSS on the success of open source projects. Using a difference-in-difference approach, the authors find that projects with a high degree of overlap with the litigated OSS suffer a larger decline in user interest (about 15%) and lower developer activity (about 45%) with respect to the control group. The decline in interest of the open source community is found to be stronger for business projects specific to the disputed OSS platform (34% greater decline in user interest and 86% less developer activity compared to the control group). Another interesting analysis about the interplay between software patents and OSS is conducted in Wen et al. (2015). The authors study the impact of the 2005 IBM decision of non assertion of patents against the OSS community and the creation of a patent common, a set of patents made available royalty-free to the community. The study shows how this "collaborative" usage of patents has increased OSS start-up entry. Wen et al. (2015) also find that the IBM decision had larger impact in the segments of the market where innovation was highly cumulative.

9. Concluding remarks

The literature on the role of patent protection in information and communication technologies has developed greatly in the last decades, in parallel with the growing importance of the ICT sectors. One of the features which has raised major concerns is the recent surge in patenting and the associated high degree of fragmentation of IP rights. Fragmentation of the scope of patenting comes hand in hand with a series of potentially problematic consequences such as patent thickets, royalty stacking, augmented patent litigation as well as difficulties in the definition of licensing terms for patents related to standardized technologies. The surge in patents has boosted the workload of patent offices, it has increased the risk of low quality patents as well as the uncertainty on technology markets.

To a certain extent, patent proliferation can be considered as a "natural" phenomena due to specific factors characterizing ICT sectors – i.e. the cumulativeness of the innovation process and the high degree of technological complexity. In recent years, these phenomena have become even more striking due to the evolving role of patents and their use as a strategic instrument and as a tool to collect royalties.

In this paper, we have reviewed the rich literature analysing the multifaceted role of patents in information and communication technologies. Our approach has been to blend academic and more policy oriented views in order to provide a comprehensive picture of the various issues at stake.

Several contributions in the literature have studied the different institutional solutions that have been adopted to deal with IP fragmentation. Patent pools represent a one-stop-shop easing access to the relevant technologies to implementers. SSOs are aiming at coordinating efforts for a smooth development of interoperable standards. Both pools and SSOs require cooperation among patent holders and industry participants and despite their role as facilitators of technology transfer, they raise concerns in two directions; first of all, as forms of horizontal agreements, they may conceal anti-competitive purposes. On top of this, they have been criticized for not defining a clear way of determining the licensing terms. SSOs members typically commit to license their patents on fair, reasonable and non-discriminatory (FRAND) terms in the attempt to moderate the market power of standard essential patents. However, FRAND commitments only define a general framework for the determination of the licensing terms and leave the identification of the exact conditions to negotiations between patent holders and implementers. As such, the definition of FRAND licensing rates remains a challenging and controversial process. In principle, patent market intermediaries – aggregators and patent assertion entities – are expected to increase market thickness, favour patent transactions and help smoothing out distortions. Nonetheless, also in this case the practical experience not always follows expectations; in particular, a strong controversy has developed on the role of patent assertion entities, often considered among the main responsible for the surge in patent litigation. PAEs are a quite novel market player; they were born essentially as an ICT phenomenon but today they are spreading their activities towards other high-tech sectors, particularly in life sciences industries. Further investigation on the role of PAEs, on their effects and consequences is highly desirable.

The controversies related with the surge in patenting are even more relevant in the case of software, probably the most important ICT segment. Software products are based on abstract computer algorithms where patenting criteria do not directly apply. Protection of computer implemented inventions is a complex matter and Europe and the US have followed different routes regarding software patentability, with this latter country adopting a more pro-patent approach; nonetheless, recent courts rulings have changed the scene and today, in the US, it has become more difficult to obtain patent protection for software applications. In a world of increasing interoperability and at the verge of Internet of Things the protection mechanisms for software and related technologies will play an even more important role in the future.

Looking forward, from our survey we can envisage several directions for further research. The theoretical literature on the role of patents in the presence of a cumulative innovation process is quite well developed. Nonetheless, much has been written on the risk of hold-up while very few contributions look at the hold-out problem, that is the practice of implementers who often infringe patents and resist patent owner demands because the odds of getting caught are small. Despite its practical relevance, the hold-out problem has been surprisingly undertheorized. On top of this, due to the difficulty in measuring the innovation cumulativeness, only few studies analyze empirically the role of patents in stimulating R&D in ICTs. As a consequence many theoretical predictions are still to be validated empirically and further research in this field is highly recommendable. The prospect of the establishment of a unitary patent system and the associated activation of a unitary patent court in Europe is also opening promising lines of research. Once implemented, the new regime will represent a genuine game changer, with potentially relevant consequences on firms' patenting strategies. One of the most intriguing open questions regards its effects on PAEs activities.

In relation to patents protecting software technologies, we foresee at least two very promising areas of research. The first one relates to the interplay between open source and patented software. As mentioned, OSS and proprietary software are two alternative ways to create and distribute software programs; the point is that their coexistence is often problematic and it is still very much unclear how to encourage an efficient interplay between them. The other promising area of research regards the role of patents in mobile applications. This market has developed very recently and today is one of the most dynamic and innovative segment in the software industry. So far, developers do not seem to have made much use of patents. Nonetheless things are changing also in this respect and a full understanding of the role of patents protecting mobile applications is highly desirable.

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