THE ROLE OF PATENTS IN INFORMATION AND COMMUNICATION TECHNOLOGIES: A SURVEY OF THE LITERATURE

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The Role of Patents in Information and Communication Technologies. A survey of the Literature.

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Abstract

During the last few decades, the number of patents in information and communication technologies has increased considerably. An increasing number of patents and the associated fragmentation of IP rights have generated a series of potentially problematic consequences. Patent thickets, royalty stacking, the emergence of patent assertion entities, increased patent litigation – particularly around standard essential patents – and the difficulties with defining fair, reasonable and non-discriminatory (FRAND) licensing terms are some of the most debated issues in the literature that we review in this paper. We devote a specific section of our survey to patent quality, currently one of the most debated issues surrounding the patent system. 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.

Keywords: patents, ICTs, cumulative innovation, FRAND, market for ideas, software.

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 had a series of consequences – patent thickets, royalty stacking, augmented litigation, difficulties in defining 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) where much of the surge in patenting has taken place and where these changes in the IP landscape are most striking.

ICTs – i.e. the set of technologies that process, store and transmit information (including telecommunication equipment, consumer electronics, computers and software products) – constitute some of the most dynamic and innovative segments of modern economies. They now permeate all aspects of our everyday lives and affect 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 the Internet of Things (i.e. the increased connectedness of individuals and things on an unprecedented scale) possible. In this extremely dynamic environment, it is crucial to understand how IP can be effectively used to stimulate and protect innovations (Comino and Manenti, 2014).

ICTs are highly heterogeneous and differ in nature and characteristics. However, they share some features that are relevant when evaluating the role of patents. They are complex technologies, which combine 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 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 emerged to cope with the increased technological complexity and to help 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 are often scrutinized by antitrust authorities (Gilbert, 2004; Lerner and Tirole, 2004 and 2008). On top of this, as witnessed by the debate on FRAND licensing, members of pools and members of standard setting organizations may have divergent interests and goals thus making it difficult for them to reach an agreement on licensing schemes (Meniere, 2015). Among the various types of intermediaries, patent assertion entities (PAEs) have drawn considerable public attention (Hagiu and Yoffie, 2013). They are alleged to be one of the causes of the surge in patent lawsuits. PAEs originated as a high-tech phenomenon and are now broadening their scope of action towards other industrial sectors such as biotech and pharmaceuticals (JRC, 2016 and FTC, 2016).

A considerable part of the increase in patenting can be ascribed to the software industry. Estimates reveal that up to one third of the patents granted by the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO) may be related to software products (Poo-Caamaño and German, 2015; Frietsch et al., 2015). 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 (Bessen and Meurer, 2008). Many 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 (Miller and Tabarrok, 2014). Differences in 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.

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 look at patent pools and standard setting organizations, the institutions that traditionally have dealt with fragmentation. Section 7 discusses the literature on the market for ICT patents, looking, in particular, at the role of intermediaries and

PAEs. We devote Section 8 to discussing the issue of patent quality focussing specifically on software patents. Finally, Section 9 offers some conclusions and ideas for future research. For each of the most relevant streams of literature we have singled out, Table 1 in the Appendix provides a list of the key contributions.

2. The surge in ICT patenting

Patent applications have increased steadily during the last few decades with sharpest increments having been registered in ICT sectors. For example, Danguy et al. (2014) documented in an empirical investigation based on data-set including information on 18 manufacturing industries in 19 countries over the period 1987-2005. These findings are confirmed also when looking to more recent data (e.g. OECD, 2014 and WIPO, 2016). The surge in patenting is common to all advanced economies, although a major role has been played by the explosion in patent filings by Chinese inventors both at home and abroad;[2] as observed by Helmers et al. (2017), this explosion is concentrated in a handful of Chinese ICT firms. Software is by and large the sector where the number of patents has increased more prominently. Poo-Caamaño and German (2015) estimate that the number of patents granted by the US patent office in 2014, for computer implemented inventions, soared to a noticeable 36.4% of the total. In a similar analysis, based on patent applications filed at the EPO from 2000 to 2010, Frietsch et al. (2015) find that more than 35% of all applications were software-related.[3]

The surge in the number of patents seems to be at odds with the results found by Graham et al. (2010) in a survey of 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, the patent system seems to be neither working particularly poorly nor well for their companies and industries; secrecy, lead time and the sale of complementary products or services are found to be more effective than patents. Interestingly, software companies consider patents as the least important mechanism to appropriate the returns of their R&D efforts. The finding that innovators do not very often perceive patents as an effective instrument to protect their innovation has been much cited in literature, ever since the well-known study by Cohen et al. (2000) was published. These contrasting figures, the surge in patenting and the scant effectiveness of patents as an appropriation mechanism, have given rise to what has been dubbed as the “patent paradox”.

This paradox can be explained by the changing role played by patents 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 have relied heavily on patents; however, firms have used them essentially as an effective means of sharing technologies and have rarely enforced them. Recently, however, much has changed. In semiconductors, and 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 one hand, large patent portfolios have been considered to be an important defensive safeguard against the possibility of rival firms taking legal action 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 several 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 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. Torrisi et al. (2016) confirm the importance of strategic motives for patenting in ICTs. They use survey data on inventors from 23 countries (European countries, Israel, the United States and Japan) who filed applications at the EPO between 2003 and 2005. The authors show that firms are not using many patents internally or for market transactions. They interpret this evidence as confirmation of the importance of strategic patenting. They also find significant differences across industrial sectors: patents are more likely to be employed strategically in complex technologies than in other areas.

Also Bessen and Hunt (2007), in a study on software patents granted by the USPTO, conclude that much of the surge in patenting is driven by strategic motives. Indeed, they observe that only a small fraction of patents is in the hands of software publishers, which in principle are the companies that develop most of the new computer programs. By contrast, three out of four software patents belong to manufacturing firms, especially those active in electronics and machinery. Based on this evidence, the two authors argue that the increase in software patenting in the US mainly reflects the greater propensity to patent of manufacturers and that there is little correspondence between research activities aimed at developing computer programs and patent ownership. An alternative explanation, to the observed distribution of the ownership of software patents, might suggest a more nuanced view with respect to that expressed by Bessen and Hunt (2007). Computer programs are increasingly embedded in hardware products and machinery in general, therefore it is quite natural for manufacturing companies to hold a growing number of software-related patents.

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

3. Patents and cumulative innovation

According to the traditional view, patents solve the free-riding problem characterizing the innovation process. Absent patent protection, the argument goes, research and development costs are borne by inventors, while innovation benefits also competitors through imitation. As a result, the incentives to develop new technologies are inefficiently low. Patents fix this free-riding problem by granting a temporary monopoly right over the new technology, thus impeding imitation and generating rents for the innovator. Patent rights also favor the private contracting of technologies and address the Arrow's appropriability problem we discuss later on in Section 7.[4]

In light of this view, the basic trade-off associated with patents is between incentives to innovate and the deadweight loss related to the monopoly position granted to the inventor. While useful in order to clarify the basic role of patents, this approach does not capture several critical features characterizing the inventive process in high-tech industries in which innovations occur sequentially and are often developed by different inventors. The cumulativeness and complexity of innovation in

ICTs make the role of patents less clear-cut, given that strengthening the protection they offer 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 briefly summarized here above.

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 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). Another potential inefficiency in the context of cumulative innovation is the reverse of hold-up, often referred to as "hold-out problem". In this case, it is the follow-on inventor/implementer who infringes a patent and opportunistically refuses to enter into a licensing agreement with the inventor. While the empirical literature has highlighted instances where hold-out has taken place (Pentheroudakis and Baron, 2017), the theoretical contributions have mainly neglected this issue.

Along with cumulative innovation, the effect of imitation on R&D incentives should also be reconsidered. Bessen and Maskin (2009) observe that imitation affects a firm's profitability in two ways. In the short-term, imitators compete with the innovator, thus reducing the profits of the latter. However, in the longer term, 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-term effect dominates the short-term one and innovation may be fostered by the possibility of imitation. Therefore, in these industries, innovation would flourish with lower levels of patent protection that would allow some degree of imitation.

The impact of patent rights on overall innovation incentives and on 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 when 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. Information asymmetry 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.

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 in both measuring cumulativeness and identifying the causal effect of patents on innovation. Galasso and Schankerman (2015) provide a notable exception. They study the impact on follow-on research of the removal of patent rights by court invalidation in the US and measure follow-on innovation using later citations. They 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. Galasso and Schankerman (2015) find that patents hinder follow-on innovation in industries characterized by complex technologies and highly fragmented patent ownership, such as computers, electronics, and medical instruments. By contrast, they find no effects in drugs, chemicals, and mechanical technologies. According to the two authors these results are consistent with the fact that technological complexity and fragmentation of IP rights complicate licensing bargaining thus potentially slowing down the innovation process. Interestingly, they provide evidence that invalidation stimulates 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 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 companies' ability to operate and forces them 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 where 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 of electrical engineering, especially telecommunications, audio-visual technology, and computer technology. Interestingly, they also find that some large ICT companies are responsible for a large share of thickets in other technological fields (e.g. instruments).

In the following paragraphs, we group the main contributions in the literature regarding the consequences of fragmentation and patent thickets into two areas.

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

The economic literature suggests that patent thickets may lead to multiple marginalizations and royalty stacking, i.e. the situation where a licensee must pay royalties to multiple parties in order to commercialize a product (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, which may reduce their incentives to use the technology. Lichtman (2006) holds a quite different view. His argument goes as follows. When the ownership of the technology is highly fragmented, each patent becomes less relevant as it protects only a small part of the whole system. This fact reduces the bargaining power of patent holders who, in turn, negotiate licensing agreements less aggressively. As a consequence, 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 of both Heller and Eisenberg, and Lichtman. As fragmentation increases, two contrasting effects emerge. On one hand, the negotiation process becomes more complex, given that the number of agreements to be signed gets larger (Heller and Eisenberg's view). On the other hand, however, negotiations for each licensing agreement speed up (Lichtman's view), since the value of each patent reduces with fragmentation. Whether fragmentation discourages or favors technology implementation depends on which effect dominates. By using data on patent disputes in district courts in the US, Galasso and Schankerman (2010) test their model by estimating how fragmentation affects the length of licensing negotiations. The authors find evidence that fragmentation accelerates the negotiation process, although the estimated effect is not strong. They interpret this evidence as moderately supporting Lichtman's argument.

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 probably 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 they will be held-up by competitors. In addition, companies may be forced to devote substantial parts of their budgets to building up large patent portfolios in order to improve 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.[5]

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 vary and depend on company characteristics and market specificities. Graevenitz et al. (2013) focus on the patenting behavior of 2,074 firms that filed 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. Firms holding large portfolios patent more intensively as thicket density increases, while 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 observe a sample of about 29 thousand UK SMEs 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; this evidence confirms again that small firms are most harmed by thickets. Cockburn et al. (2010) find that the impact of fragmentation on companies varies 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 that need to license rivals' technology. By contrast, for companies that do not in-license, the greater the fragmentation, the larger their share of sales from new products. A noteworthy analysis specific to the software industry is in Noel and Schankerman (2013). These authors too find contrasting evidence on the impact of fragmentation of IP rights. On the one side, they show that fragmentation increases R&D and patenting by firms – due to their need to build up an arsenal of patents to resolve disputes - but, on the other, it lowers firms stock market value because of the larger transaction costs it generates.

5. Patent pools

Historically, patent pools and standard setting organizations (SSOs) provide the two means used by market participants to cope with IP fragmentation. 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 thickets and are seen as a potential solution to inefficiencies resulting from fragmented and overlapping patents.[6]

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. Indeed, an increasing number of antitrust cases deal with patent pooling arrangements (Gilbert, 2004). In this respect, two interrelated issues are relevant to an evaluation of the effects of patent pools. The first is the degree of substitutability or complementarity of patents forming the pool; the second is 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, but 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-competition. This is because members internalize the fact 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) point out 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 extent to which prospective licensors can invent around, whether they can invalidate patents, or whether pool members can 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 that when the pool aims to increase royalties (as in the case of substitutes patents), independent licensing restores competition among pool members and therefore it is welfare enhancing. On the other hand, with complementary patents, competition in royalties produces no effect. Lerner and Tirole’s arguments support the approach followed by competition authorities, which often impose independent licensing on pool members. The authors, in fact, suggest that independent licensing reduces profitability of “bad” pools, i.e. pools that aim to increase royalties.

Another issue, extensively studied in the literature, is the effect of “grant-back” clauses. A grant-back clause requires pool members to disclose and transfer all improvements made to the licensed technology for free, or at a low price.[7] This 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 member from other 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. Historical evidence is in Lampe and Moser (2010, and 2014). The authors investigate the effects of patent pools on innovation incentives looking at the sewing machine industry in the late 19th century. The authors find that the sewing machine pool induced a reduction in patenting and innovation of member firms and diverted research efforts towards an inferior substitute technology. 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. This study also finds that pools have a negative effect on innovation, with outsider firms innovating less after the pool formation. However, when he looked at the underlying mechanisms driving this result, Vakili (2012) observed that the reduction in innovation rates was 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 the firms' own products. Baron and Pohlmann (2015), however, question the idea that pools have a negative effect on innovation incentives. According to these 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 and FRAND licensing

Formal standard setting is the other traditional institutional arrangement used to cope with the inefficiencies of fragmentation. Standards are ubiquitous in ICT industries due to the strong need for interoperability. Typically, Standard Setting Organizations (SSOs) are formed by industry stakeholders who endorse a particular technology and promote its adoption among market participants (Simcoe, 2011). Standards aim to facilitate 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 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).

The debate on FRAND licensing

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 in both the development and the implementation of the standard. These vertically integrated companies typically ended-up cross-licensing their SEPs, thus paying few royalties to each other. Today, by contrast, 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 having 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 for 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. Indeed, 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 value it would have been given in an auction prior (ex-ante) to the definition of the standard. Though theoretically elegant, this proposal has some practical problems. First of all, the royalty rates are actually set ex-post, when the standard is at the commercialization stage. Hence, 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, standard setting 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 is 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 to many users with different needs and preferences, there is no unique incremental value – it is, instead, 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. Instead, 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, allowing parties the ability to tailor the agreements to their specificities may be efficient, on the other side, it comes at the cost of increasing uncertainty (Meniere, 2015). Practitioners and industry experts argue in favor of FRAND flexibility, but they also recognize that some limitations might help in reducing uncertainty and the associated transaction costs. It remains unclear how strike the right balance between these contrasting goals. Meniere (2015) lists a set of possible interventions aimed to improve the efficacy of FRAND restrictions, such as the disclosure of information regarding previous licensing agreements on SEPs; the availability of this information 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 that patent holders should be made to commit to a maximum royalty before the definition of the standard. Like Swanson and Baumol (2005), they argue that ex-ante competition in royalty caps among technologies willing to be included in the standard would be a way of restoring efficiency. In theory, the commitment to royalty caps proposed by Lerner and Tirole (2015) would make FRAND provisions redundant. Nonetheless, the impossibility of identifying all the relevant technologies limits the efficacy of royalty caps, and makes the adoption of FRAND commitments necessary anyway. Lerner and Tirole therefore believe that royalty caps and FRAND commitments would complement each other.[8]

A different issue that has attracted the attention in the economic literature on standard setting is the quality of SEPs. This discussion has been fuelled by the recent "smartphone war" – discussed later in the survey – many see as been caused by the presence of essential patents of low quality. Regibeau et al. (2016) suggest that a significant declaration fee for SEPs should be charged and regular essentiality tests should be carried out on a random sample of SEPs. Testing essentiality of SEPs would raise their quality and could contribute to considerable reduction in 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, Blind and Pohlmann (2016) suggest that the European Patent Office might carry out SEPs tests. 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 the high quality of SEPs, and of SSOs performing well in selecting technologies with higher inherent merit.

The role of courts in FRAND licensing

A related contention is the role played by the courts when licensing negotiations fail. In the US, the 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 an approach based on a hypothetical negotiation appears to be quite difficult to be implemented in practice. European courts, however, focus more on the conduct of parties during negotiations and they specifically assess whether patent holders have complied with the obligations imposed by FRAND commitments. Differences between the two sides of the Atlantic also exist as regards the imposition of injunctions. Traditionally, US courts have been reluctant to grant injunctive reliefs to SEP owners committed to FRAND licensing whereas European courts have been more prone to conceding injunctions. However, things changed after the 2015 decision of the Court of Justice of the European Union in Huawei *vs* ZTE (Baron et al., 2016b). This ruling limits the possibility of seeking injunctive relief by specifying a set of requirements that must be fulfilled by the SEP owner. Specifically, before seeking 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 to speed up the standardization process and, as such, to improve market efficiency, they may have undesired effects on their members' incentives to innovate. Often companies contributing to the standard adhere to informal consortia to supplement the formal standard setting process. Baron et al. study how these consortia can help coordinating R&D efforts and thus mitigate 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 a consortium. However, this effect disappears, or 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) use information collected within the 2011 German Community Innovation Survey to study the effect of formal standard organizations on firms' innovative efficiency, measured in terms of the resources needed to innovate. They find that SSOs have a detrimental effect on innovation efficiency in mature markets in which companies operate in an environment characterized by a low degree of uncertainty. According to Blind et al. (2017), in such an environment, few standard setting firms are able to align the standard with their technological preferences. This fact raises the costs of other firms to comply with the standard, thus reducing their innovation efficiency. In case of high market uncertainty, SSOs are found to have an opposite effect. Highly dynamic environments are intrinsically unstable and different technological paths often compete with each other. In such markets, SSOs have a positive effect on innovation as they indicate the direction for further technological developments and reduce uncertainty.

7. The market for ICT patents

Technology transactions are inherently complicated because of the Arrow's appropriability problem (Arrow, 1962). Potential buyers need to obtain detailed information about the technology and its functioning before the purchase. In turn, sellers of the technology are reluctant to reveal this information in great details because they fear to be imitated. Patents solve Arrow's dilemma as they make imitation illegal and, as a consequence, they favor the development of the market for technologies. As already mentioned in Section 3, a well-functioning market for technologies is crucial in order to provide the correct R&D incentives for the whole sequence of innovators in the context of cumulative innovation (Green and Scotchmer, 1995). Available evidence suggests that technology-related transactions have grown considerably during the last few years (see Arora and Gambardella, 2010 for a survey). Recent figures reveal that cross-country licensing for patents, trademarks and copyright increased in the OECD area by an average annual rate of 10.6% between 2000 and 2010, well above the rate of growth of GDP over the same period (OECD, 2012). 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).

Despite the remarkable growth registered during recent years, the market for patents appears to be prone to failures.[10] Drawing from the literature on market design, Gans and Stern (2010) identify several potential inefficiencies, which are often exacerbated by the peculiar features of ICT industries. 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 this, the cost of searching and identifying potential buyers or sellers of the technology is substantial – and increasingly so as the number of patents reading on the relevant technologies may be extremely large. The lack of transparency in patent transactions has been recognized by industry experts and analysts as one of the major impediments to the development of the market for patents. Indeed, 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 problem is so severe that the USPTO has recently made available information on reassignments on Google Patents. These data reveal changes in patent ownership since the year 1980 (see Akcigit et al., 2015). The market itself is coming up with new solutions, like the recently initiated Avanci.com platform for the licensing of wireless technologies, which aims to help developers and implementers disentangle what technology rights they need and how to get them.

Finally, another source of friction in technology markets is related to the fact that patents 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).

Patent intermediaries

Several entities facilitating the matching between demand and supply of technologies may, in principle, play a crucial role in curbing the inefficiencies characterizing patent markets. These intermediaries range from brokers – acting as simple middlemen between potential licensors and licensees – to aggregators purchasing innovations and then licensing them to practicing firms, from online marketplaces where patent rights are auctioned to more traditional intermediaries such as pools and SSOs. Intermediaries play a particularly important role in the case of ICTs where the need to promote standardization is critical to innovation and allowing prospective licensees to easily access technologies is deemed as essential (Yanagisawa and Guellec, 2009).

A recent stream of literature has analyzed the impact of intermediaries on the efficiency of patent markets (e.g. Agrawal et al., 2016 and Haber and Werfel, 2016) or on firms R&D incentives (e.g. Penin, 2012 and Benassi and Geenen, 2013). While these contributions are mostly theoretical, the empirical and practical literature is comparatively less developed. 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 marginalization/royalty stacking problems, which substantially limit the scope for technology licensing. More recent forms of intermediaries (patent auctions and online patent marketplaces) are unlikely to fix inefficiencies either because they fail to increase market thickness or because they are inherently unable to address the Arrow's classic appropriability problem.

According to Hagiu and Yoffie (2013), patent aggregators constitute a more promising type of intermediary. These authors distinguish between defensive aggregators and super-aggregators. Defensive aggregators offer their clients a sort of “insurance” against the risk of being 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 of licensing revenues. As regards the latter, 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 holds approximately 40,000 patents concentrated in ICT sectors - one of the largest patent portfolios in the world. 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 in the market for ideas. PAEs are generally referred to as entities that acquire patents from third parties and exploit them in order to maximize earnings from licensing and litigation (see Schwartz and Kesan, 2014; Cohen et al., 2015). 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 largely 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), representing a marked increase on previous years. In Europe, PAEs appear to constitute 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. The legal fragmentation of patent protection under the existing European patent system discourages 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 allocation 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 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, 201; 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.

A recent report by the Federal Trade Commission provides an overview of PAE activity in the US and the Joint Research Centre of the European Commission provides a similar overview of their activities in Europe (FTC, 2016; 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. The FTC (2016) distinguishes between “Portfolio” and “Litigation” PAEs depending on their business model. The former tends to be strongly capitalized and to purchase patents outright. They negotiate high-stake licensing deals (worth millions of dollars) covering large patent portfolios. Litigation PAEs 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 that closely approximates the lower bounds of litigation costs (FTC, 2016). This corroborates the hypothesis that this form of PAEs is mainly involved in nuisance litigation. The ICT sectors are the most affected in both Europe and the US, though recent evidence reveals that PAEs are now moving into other sectors, such as pharmaceutical and biotech (Feldman and Nicholson Price, 2013). According to the FTC (2016), nearly nine out of ten 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 business, 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. Neither the FTC nor the JRC reports can confirm that PAE activity has a large-scale impact 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 less PAEs activity and less litigation in Europe than in 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 across Europe. The unified patent court, in turn, will be responsible for rulings in disputes regarding unitary patents. It is unclear at the moment whether this regime will provide more or fewer business opportunities for PAEs. It is recognized that the alleged advantages of the new European system – e.g. the reduction in patenting costs – may favor PAE activity. However, much will depend on whether patents continue to be of high quality, and on the establishment of a new high quality court system (Thumm, 2018).

Cohen et al. (2015) present interesting evidence that may help to shed light on PAEs' controversial role. The authors carried out a large-sample study based on the complete universe of PAEs litigation activity in the United States between 2005 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 other hand, 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 in which 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 run no risk of being counter-suited (de Bisthoven, 2013).

There is an ongoing and intense debate on what impact PAEs have on firms' innovation and on technology diffusion. As highlighted by the FTC (2016) and the JRC (2016), PAE activity typically does not involve any technological transfer given that patent license or litigation usually occurs after the relevant product 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; JRC, 2016). Cohen et al. (2015) take a different view; they 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 litigation, the reduction is estimated to be around 20%. Clearly, as the authors observe, for an overall evaluation of the consequences of PAE litigation on innovation one should also consider that assertion entities may 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 small part of the damages cashed by PAEs (Bessen et al., 2012; 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. Kiebzak et al. (2016) analyze 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. Patent quality

One of the most debated issues surrounding the patent system is related to the quality of granted patents. "Quality" is seen 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). A decline in patent quality increases transaction and litigation costs, thus endangering the functioning of the patent system as a whole and potentially slowing down the pace of technological progress. The discussion on patent quality has been fuelled by the influential book by Jaffe and Lerner (2004) where it is argued that the USPTO has been issuing a significant number of patents likely to be invalid.[11] From a theoretical point of view, the effects of low quality patents are analyzed in Farrell and Shapiro (2008). The authors show that low-quality patents may generate two forms of inefficiencies. On one hand, there is a free-riding effect, which reduces the incentives to go to Court 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, even the low quality ones, allow patent holders to set fees strategically in an attempt to reduce competition among implementers, thus maximizing licensing revenues and substantially lowering consumer surplus.[12]

The alleged decrease in patents quality is usually associated with the surge in applications. Under the pressure of increasing backlogs, there is a danger that patent examiners devote less time on searching and examining applications and this might reduce the quality of granted patents.[13] The fragmentation of IP rights, typical of ICT sectors, exacerbates the problems associated with the mounting number of applications. Another relevant determinant of the reduced quality of patents can be attributed to the explosion of software patents whose boundaries and validity are often unclear, as we discuss below.

Clearly, an important role in ensuring the quality of granted patents is played by patent offices. For this reason, a growing body of literature has focused on the procedures patent offices adopt; a particular attention has been devoted to the schemes employed to remunerate patent examiners. Providing examiners with the appropriate incentives to carefully screen applications and verify the fulfillment of the patentability requirements is a complex matter. In principle, examiners should review the largest possible number of applications and, at the same time, they should ensure that only high quality patents are granted. However, while the numbers of patent applications filed and patents granted can easily be verified, the quality of the applications and the patents granted is much more difficult to monitor. An interesting theoretical contribution in this field is in Schuett (2013). The author proposes a theoretical model studying under which conditions quantity-based compensations provide the correct incentives for an examiner to both exert effort in evaluating applications and to truthfully reveal the evidence she/he finds (or lack thereof). Eckert and Langinier (2014) review the literature, both theoretical and empirical, analyzing the role played by the procedures adopted by patent offices. They look not only at the behavior of examiners and at the impact of different rewarding schemes, but also at the filing strategies of applicants as well as at the behavior of third parties who may oppose the granting of patents and reveal relevant information regarding prior art.[14]

An interesting analysis on patent quality has been recently proposed by de Rassenfosse et al. (2016). The authors evaluate the quality of patents by comparing the decisions of the five largest PTOs (in China, Europe, Japan, Korea, US) on the protection of the same innovation. They distinguish between two conceptually distinct reasons why low quality patents may be granted: i) the examination process is superficial so that undeserved (i.e. patents inconsistent with the patent offices' own standards) and potentially invalid patents are granted, and ii) patent offices systematically apply too lenient standards for patentability. Based on a sample of more than 400 thousand applications, the authors find that 2-6% patents are inconsistent with the patent office’s own standard and 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 office being applied. The Japanese patent office is found to have the tightest standard for patentability while US and China the loosest. Interestingly, the authors find that the share of patents of dubious validity is higher in frontier industries such as software and biotechnology. The lower quality of Chinese patents is also confirmed by Boeing and Mueller (2015); the two authors construct an index of quality based on patent citations that allows them to compare Chinese applications with those from high-income countries. They found that for the applications with Chinese origin the average quality index is only one third of that achieved by other applications.

Concerns about quality are common to many sectors but they are certainly at their maximum in software. The low quality of software patents is seen as one of the major responsible for the increased litigation rates and it is considered at the heart of the smartphone war we briefly address below. Discussions about the quality of software patents involve researchers as well as policy experts; the issue is so serious that the mere patentability of computer-implemented inventions is at the center of an intense debate. In the following section we present the main contributions of this broad literature and we start by quickly discussing the related issue of the patentability of software programs.

The patentability of computer implemented inventions and the quality of software patents

Computer algorithms are protected by copyright and were not originally a patentable subject matter. In the early days of the computer industry, companies did not consider software as a product per se, but distributed 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 court decisions, in the US the patentability of computer programs was broadened. Since the mid '90s, software related-inventions have been treated in the same way as inventions in any other technological field.[15] This pro-software patent regime has led to an exponential growth in the number of patents granted by dPTO. Nonetheless, some recent rulings are changing the scene and today, in the US, it is more difficult to obtain patent protection for software applications.[16] Interestingly, SIPO, the China's State Intellectual Property Office, is apparently moving in the opposite direction; the revised guidelines published in October 2016 create a more favorable environment for software patenting (Brachmann, 2017). In Europe, the legal framework appears to be quite stable, without significant changes over the last years. The European Patent Convention excludes computer programs claimed "as-such" from patentability. For a computer program to be patentable, it needs to produce what is known as the "technical effect", i.e. to solve a technical problem in a novel and non-obvious manner (EPO, 2014). The controversies about the role of patents in computer programming are related to the particular 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.

A second important feature of software is the high level of abstraction of 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-coloring 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 may be difficult to ascertain whether a new software program is actually novel and non-obvious.

One of the main concerns with software patents regards their quality. A series of studies has been conducted in the US and, with few exceptions (Allison and Mann, 2007; Graham and Vishnubhakat, 2013), there is a general consensus that software patents are of a lower quality than 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.[17] 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 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 "means-plus function" claiming. US patent law allows claims that specify 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 and has ended-up in specifying very generic means such as "a computer" or "a data processing system". This interpretation of US courts imposes very few 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 to search the prior art, thus increasing uncertainty about the validity of granted patents.

Smartphone wars

In 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 legal actions reached unprecedented numbers: 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". It represents a clear example of the possible consequences of the joint effect of the strategic use of patents and of the dubious validity of some of the granted patents. It is widely believed that the root cause of this surge in litigation lies in the poor quality of ICT patents and of software specifically. This view is not, however, shared by everybody; 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 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 probably invalid. According to Graham and Vishnubhakat, the fact that about 80% of the asserted patents (17 out of 21) were, instead, declared valid (or likely to be so) by courts is 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 an acceptable proportion of invalid patents. This is even more the case if one considers that the patents being asserted are likely to be of higher quality than the average software patents. Indeed, smartphone war litigants are large and established ICT practicing companies that 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 as being a corollary of the technological complexity of ICTs. More 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 fact that IP rights are not self-enforced. Indeed, 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.

9. Concluding remarks and future research

The literature on the role of patent protection in information and communication technologies has grown considerably over the last few decades. One of the features that have raised major concerns is the surge in patenting and the associated high degree of fragmentation of IP rights. Fragmentation of the scope of patenting comes with a series of potentially problematic consequences such as patent thickets, royalty stacking, augmented patent litigation and difficulties in defining licensing terms for patents related to standardized technologies. In parallel with the growing importance of the ICT sectors, the surge in patents has boosted the workload of patent offices. It has also increased the risk of low quality patents and the uncertainty on technology markets.

To a certain extent, patent proliferation can be considered as a “natural” phenomenon due to specific factors that characterize the ICT sector – i.e. the cumulativeness of the innovation process and the high degree of technological complexity. In recent years, this phenomenon has become even more striking due to the evolving role of patents, always more often used as a strategic instrument and as a tool to collect royalties.

Our survey indicates several avenues for further research. The theoretical literature on the role of patents in the presence of a cumulative innovation process is quite well developed. However, much has been written on the risk of hold-up while very few contributions look at the hold-out problem, namely the practice of implementers who infringe patents and resist patent owner demands because the odds of getting caught are small (Pentheroudakis and Baron, 2017). Despite their practical relevance, the hold-out and hold-up problems have been under-investigated empirically. On top of this, due to the difficulty in measuring the cumulativeness of innovation, few studies analyze empirically the role of patents in stimulating R&D in ICTs. As a consequence, many theoretical predictions have yet to be validated empirically and further research in this field is highly recommended. Empirical research on the governance of SSOs and the interplay with the patent system in the ICT sector is also needed. Similarly, the analysis of IP policies of standard setting organizations and patent pools and their consequences on the incentives to innovate deserves further empirical research. While the theoretical implications are often well spelled out (e.g. Lerner and Tirole, 2004 and 2008; Meniere, 2015), empirical studies are more limited.

Our review has highlighted that while the market for technologies has been growing during the last years, significant failures still limit its scope (Arora and Gambardella, 2010; Gans and Stern, 2010). By facilitating the matching between demand and supply of technologies, intermediaries can play a critical role. Also in this respect, we found that the majority of contributions studying intermediaries are theoretical. Additional research should shed light on their functioning and business models. Furthermore, while different authors have studied the determinants of the decision of patent-holders of whether to license their technologies (e.g. Caviggioli and Ughetto, 2013), less is known regarding the adoption of specific governance modes; for instance, more insights should be gained on the factors that induce innovators to commercialize technologies via intermediaries. This would also clarify the role and the benefits that patent intermediaries bring to the market. Among intermediaries, patent assertion entities are considered to be the most controversial ones (Hagiu and Yoffie, 2013). PAEs are often viewed as one of the major responsible for the surge in litigation even though, in principle, they may play positive roles in the market for technologies. On the one side, they may increase market thickness; on the other side they can help individual inventors and SMEs in negotiating more effectively with large and powerful manufacturers (see Haber and Werfel, 2016, for laboratory-based experimental evidence). Further investigation on the role of PAEs, their functioning, and their impact on patent markets is needed, also in light of their evolving nature and of the major regulatory reform that is taking place in Europe. Born essentially as an ICT phenomenon, today PAEs are spreading their activities towards other high-tech sectors. Also in terms of the geographical scope, things are changing; traditionally, PAEs have been operating mainly in the US but, as we have documented, they are becoming now more active in Europe (Love et al., 2017) and, recently, also in China (Robinson, 2016). In Europe the prospect of the establishment of a unitary patent system and the associated activation of a unitary patent court is also opening promising lines of research. Once implemented, the new regime will represent a genuine game changer; it will coexist with the other routes companies may follow in order to apply for patent protection, opening new opportunities for firms' patenting strategies (Love et al., 2017). One of the most intriguing questions regards the effects of the change in the regulatory framework on PAEs activities. As a matter of fact, some of the features of the new system – the alleged reduction in patenting costs and the more effective enforcement of rights that the unitary patent system is supposed to deliver – may potentially favor PAEs activity in Europe and the future will very much depend on the actual implementation of the new system (Thumm, 2018). Another line of research will have to look empirically into the quality of the patents asserted by PAEs.

Another aspect that deserves further investigation is the role of China and Chinese patenting in IP markets. As a matter of fact, nowadays, the SIPO, the Chinese patent office, is the one receiving the largest number of applications worldwide (WIPO, 2017). Chinese patenting represents one of the main drivers of today's IP markets with major impacts on the economic landscape, especially in ICTs where much of applications are concentrated. One of the most delicate issues relates to the quality of patents issued by the SIPO. As we have discussed in the paper, international comparisons reveal that patents granted in China are still of comparatively lower quality than patents granted by other patent offices. Despite the increasing role of Chinese patents, existing contributions in the academic literature are limited in numbers and this certainly calls for more in-depth analyses in this field.

Among the ICTs, software is certainly one of the most interesting sectors to investigate. Software is a general-purpose technology that is often embedded in new products and machineries and, 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. One of the most critical issues is related to the quality of software patents. The high degree of abstractness of the underlying technology makes it difficult to ascertain whether a new program fulfils the patentability requirements (Bessen and Meurer, 2008). On top of this, being potentially embedded in products belonging to the most diverse technological areas, is even harder for examiners to verify the novelty and non-obviousness of software related inventions. The presence of a significant fraction of patents of dubious validity may reduce the pace of technological progress. As distinctly shown by the smartphone war, allegations of patent infringement may generate high stakes litigations. In this view, we believe that further analysis on the consequences of the low quality patents on litigation and on firms incentives to innovate would be very welcomed. Relatedly, another very promising area of research is the interplay between proprietary/patented software and open source (OS), an alternative mode of developing and distributing computer programs that has made inroads into several segments of the industry (Comino and Manenti, 2014). Based on the principle that the source code should be made available for re-use and distribution, the OS development model faces the risk of being inhibited by the increasing number of patents protecting proprietary software. As a matter of fact, the difficult coexistence between proprietary and open source has already become evident in the processes of formal ICT standard setting. Most SSOs use FRAND licensing terms, while the most used open source license – the General Public License – is incompatible with these terms (Li, 2017).

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Appendix

Literature streams	Key contributions	Specific issue
Surge in ICT patenting	Dunguy et al. (2014) Helmers et al. (2017)	Increasing number of patent applications, mostly concentrated in ICTs
	Frietsch et al. (2015) Bessen and Hunt (2007)	Increasing number of software patents
Changing role of patents	Hall and Ziedonis (2001)	Patents as "bargaining chips" in licensing negotiations
	Cohen, et al. (2000) Graham et al. (2010)	Role of different appropriation mechanisms for innovation incentives
	Cockburn and MacGarvie (2009, 2011)	Patents as signals for VCs
Patents and the cumulative nature of innovations	Green and Scotchmer (1995) Bessen and Maskin (2009)	Theoretical studies on the role of patents when innovation is cumulative
	Galasso and Shankerman (2015)	Causal effect of patents on innovation
Fragmentation (patent thickets) and royalty stacking	Shapiro (2001) Heller and Eisenberg (1998)	Economic analysis of patent thickets: double marginalization, royalty stacking, the tragedy of anticommons
	Galasso and Schankerman (2010)	Empirical analysis on the effect of fragmentation (thickets)
Fragmentation (patent thickets) and innovation	Graevenitz et al. (2013)	Consequences of thickets on patenting incentives
	Noel and Schankerman (2013)	Impact of thickets on R&D in software industry
Patent pools	Lerner and Tirole (2004, 2008) Gilbert (2004)	Economic analysis of patent pools and related antitrust issues
	Baron and Pohlmann (2015)	Effect of pools on firms' patenting activities
FRAND licensing	Meniere (2015)	Overview of the main issues related to FRAND licensing
	Lerner and Tirole (2015)	Theoretical analysis of the licensing terms of SEPs
	Swanson and Baumol (2005)	On incremental value for remunerating SEPs
SSOs and innovation	Baron et al. (2014) Blind et al. (2017)	The effect of SSOs on the incentives to innovate
The market for ICT patents	Arora and Gambardella (2010) Gans and Stern (2010)	Extent and limits of the market for patents
Patent intermediaries and PAEs	Hagiu and Yoffie (2013)	Traditional and emergent patent intermediaries
	FTC (2016); JRC (2016)	Policy reports on PAEs in US and EU
	Cohen et al. (2015)	Empirical analysis on PAEs behavior
Patent quality	Jaffe and Lerner (2004) Farrell and Shapiro (2008)	On the effects of decreasing patent quality
	Eckert and Langinier (2014)	Patent quality: the role of PTOs'

		procedures
	de Rassenfosse et al. (2016)	The quality of patents at the five largest PTOs
	Graham and Vishnubhakat (2013) Miller (2014) Bessen and Meurer (2008)	On the quality of software patents

Table 1: literature streams and key contributions

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[2] According to Dang and Motohashi (2015) a major determinant in the increase in patent filings by Chinese firms is the patent subsidy program implemented since the late '90s by the Chinese government.

[3] 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; 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).

[4] The positive role of patents is stimulating innovation is a highly debated issue in the economic literature. Machlup and Penrose (1950) provide and interesting historical account. A vibrant criticism against the traditional view of patents and IP rights comes from the recent works of Boldrin and Levine (see Boldrin and Levine, 2008). See Comino and Manenti (2014) for a discussion on these issues.

[5] 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).

[6] Lampe and Moser (2010) investigate the effects of patent pools on innovation incentives by using historical data on the sewing machine industry of the late 19th century. The authors find that pools induced a reduction in patenting and innovation of member firms.

[7] For a study on the use of grant-back clauses in licensing contracts, not necessarily related to patent pools, see Laursen et al. (2017). Employing data on nearly four hundred licensing agreements in the pharmaceutical industry, the authors find that the contract is more (less) likely to include a grant-back clause the closer the licensed technology to the licensor's (licensee's) core patented technologies.

[8] It deserves to be noted that the focus of this stream of literature is on the analysis of how the bargaining power granted by patents changes before (ex-ante) and after (ex-post) their inclusion into the standard. Less attention is devoted to studying how different licensing restrictions (FRAND commitments, ex-ante determined royalty caps, etc.) affect the incentives to innovate.

[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 US 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.

[10] The theoretical literature moving from Green and Scotchmer (1995) has highlighted the crucial role of information symmetry for the efficiency of patent transactions (see Bessen, 2004). Comino et al. (2011) 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.

[11] 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.

[12] PTOs issuing low quality patents may generate another undesirable consequence, as suggested by Comino and Graziano (2015). The presence of patents of dubious validity reduces the ability of firms to use patents to signal their quality vis a vis venture capitalists or other potential investors.

[13] Pendency and backlogs increased despite the fact that most PTOs have hired new staff in order to improve their examination capacity (see WIPO, 2017).

[14] de Rassenfosse and Van Pottelsberghe (2013) review the literature on the role of fees in the patent system and suggest that low pre-grant fees may cause congestion and increase incentives for low quality applications.

[15] 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).

[16] 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).

[17] 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.