FRAND commitment and standard adoption

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Abstract

FRAND (Fair, Reasonable and Non-Discriminatory) terms are often used in standard adoption relying on patent pooling. They require holders of patents included in the pool to commit ex-ante that they will charge fair, reasonable and non-discriminatory royalties for their patents after the standard is adopted. The present paper shows that they may stimulate the standard adoption and be beneficial for the consumers. This is because FRAND terms may constitute a necessary condition for holders of patents for unique technological solutions to join a standard setting agreement. When the standard adoption leads to the exclusion of competing technological solutions, FRAND terms may help to avoid situations in which the holder of a patent facing ex-ante competition abuses its market power after the standard adoption. In particular, they may help to avoid excessive royalties charged by the holders of the ex-ante replaceable patents and downstream market foreclosure. Given that those potential abuses may be at the expense of holders of the ex-ante irreplaceable patents, a standard setting agreement may be difficult to reach in absence of FRAND terms. Hence, FRAND terms may be necessary to assure that the standard setting agreement is reached and the standard is adopted. Such a standard adoption relying on FRAND terms may be beneficial for the consumers by generating network externalities or decreasing the final price.

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1 Introduction

Technological standards help consumers to benefit from network externalities. For, example it is more convenient for the consumers if movies are recorded in only one movie format. If that is the case, there is no need to wonder which movie reader to buy and to worry that a desired movie will be recorded in the format that is incompatible with the purchased movie reader. Furthermore,

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having one movie standard may enable sharing opinions between movie fans, which in turn may stimulate further demand for movies. Finally, by increasing the number of potential viewers, introduction of a standard for movie recording may encourage the producers to record more movies.

Standard setting organizations recognize beneficial effects of technological standards and promote standard setting. They serve as a platform for different developers of technologies, potential users and developers of complementary products. By giving all the concerned parties the possibility to communicate, they enable selecting the most convenient technological solutions and developing new technologies. Developers of technologies may jointly seek ways how to combine their technological solutions in order to create a new technology. Potential users may express their needs regarding the emerging standard. Finally, developers of complementary products may become better informed about the technological specifications of the emerging technology and start developing compatible complementary technologies before the standard emerges.

Technological standards may involve patent pooling. If an emerging standard relies on the state-of-the-art technology, it is very likely that its components are patented by different companies. In that case, various patent holders may pool their patents to create a joint license. An interested user faces then a possibility of licensing the entire standard and paying a joint royalty that is later divided between the relevant patent holders.

As patent pooling often relies on incomplete contracts, it may introduce a hold-up problem. The hold-up problem may occur when contracts specifying patent pools do not determine the royalties. Then, if the standard adoption increases the market power of the involved patent holders, they may behave less aggressively ex-post than they would behave ex-ante. The increased market power may result from the elimination of the technological solutions that could potentially replace the solutions used in the standard. Such a market foreclosure may occur in the presence of specific irreversible investments, network effects, development of complementary products, customer lock-in or high switching cost. As a result of the disappearance of the alternative technological solutions to the ones used in the standard, holders of patents that faced ex-ante competition may gain additional market power and abuse it. For example, they may charge higher royalties. This potential abuse of the supplementary market power gained after the standard adoption is often referred to as the hold-up problem.

Standard setting organizations promote the use of a contractual arrangement known as the FRAND commitment in order to eliminate the potential hold-up problem. The FRAND commitment stands for Fair Reasonable And Non-Discriminatory licensing terms. By adopting FRAND terms, patent holders commit to set ex-post fair, reasonable and non-discriminatory royalties. This contractual arrangement allows patent holders not to commit to the exact level of royalties ex-ante, which would be very difficult, given that the economic value of the standard is often not known before the standard emerges. Instead, they commit that the royalties that they will set ex-post will not be unfair, unreasonable or discriminatory.

Several economists believe that FRAND terms may be interpreted as the terms that would have been negotiated ex-ante (before the elimination of the ex-ante competition), if the value of the standard was then known (see Farell et al., 2007). In other words, FRAND terms may be interpreted as royalties to which parties would commit ex-ante if they had information that is normally available ex-post.

The present paper proposes a theoretical model studying the standard adoption in the presence of network externalities and FRAND terms. It asks the following question: what is the impact of the FRAND commitment on the standard adoption? It also asks a complementary question: is standard adoption beneficial for the consumers in the presence of network externalities and FRAND terms?

In the proposed theoretical model, there are three patents: two of them are competing, substitutable and replaceable patents and one is a complementary, irreplaceable patent. A single technology may be created using one of the competing patents and the complementary patent. Hence, there may be either one standard (one of the two competing patents plus the irreplaceable patent) or two competing technologies (each competing patent combined with the irreplaceable patent). The created technologies or the emerged standard are used to produce the final good by two downstream producers.

The proposed model allows for an emergence of a potential hold-up problem. If a standard is adopted, the unused replaceable patent becomes unavailable. This disappearance of alternative technological solutions seems to fit well the reality and may be explained in practice by high technology adoption costs, high switching costs or customer lock-in. In the model, it may give additional market power to the holder of the remaining replaceable patent which if abused may result in excessive royalties.

In practice, the FRAND terms are used to address this hold-up problem. In the model, in the presence of FRAND terms, the royalty for the ex-ante replaceable patent is set at the level that would be set before the disappearance of the competing patent. This implies that once FRAND terms are used in the standard setting agreement, the holder of one of the ex-ante replaceable competing patents will set its license fee at the level of its marginal costs.

The potential effects of the FRAND terms on adoption of a standard are analyzed for the vertically integrated firms. In particular, in the model each holder of one of the two competing patents is vertically integrated with a different downstream producer. In other words, the present paper proposes a stylized model in which each downstream producer possesses its own technology which combined with the technology of the single upstream firm may be used to produce the final good. Hence, this model can be interpreted as an introduction of a technical innovation to a given industry. This innovation may be used by the downstream producers together with their production facilities.

The use of the upstream patent is insufficient to assure interoperability between two competing technologies. If downstream firms use the patent offered by the upstream unintegrated company together with their individual production facilities, their products will not be interoperable. Otherwise, if they adopt a

standard based on one of the competing technologies and the technology offered by the upstream unintegrated company, their products will be interoperable and consumers will benefit from higher network externalities.

Adoption of a standard is potentially beneficial for the consumers because of the network externalities. In the model, the value of a given technology for a single consumer increases, as more other consumers use it. The adoption of a standard may increase the number of consumers of a given technology and therefore increase the utility of a single consumer using this technology. The overall effect depends on the number of users of a given technology and the retail price of the good based on this technology.

The proposed model shows that a standard setting agreement may be never reached if FRAND terms are not employed. This is because, in the absence of the FRAND commitment, the adoption of a standard leads to the abuse of market power by the holder of the ex-ante replaceable patent. This hold-up problem hurts consumers, who have to pay higher retail price, and the competing downstream producer, who may be forced to leave the downstream market. The potential downstream foreclosure has in turn a negative effect on the profits of the holder of the ex-ante irreplaceable patent. Facing no competition, the remaining downstream producer may be eager to restrict its supply, harming the profit of the holder of the unique irreplaceable patent. Given this negative effect on its profit, the holder of the ex-ante irreplaceable patent may not be willing to sign a standard-setting agreement without FRAND terms.

Application of FRAND terms assures the adoption of a standard. In the presence of FRAND commitment, the royalty set by the ex-ante replaceable patent is reasonable, letting the other downstream producer stay in the market. The resulting competition between two downstream producers will lead to sufficient profits for the holder of the ex-ante irreplaceable patent. Furthermore, these profits will be even higher than in the absence of the standard, as the holder of the ex-ante irreplaceable patent will be able to extract part of the rent generated by the network externalities, leaving the other part for the downstream producers and consumers. Therefore, the holder of the irreplaceable patent is willing to join a standard setting agreement if it includes the FRAND terms. Consumers benefit from the standard adoption if FRAND terms are employed. By increasing the number of users of the selected technology, the standard adoption increases the utility of a single consumer through the network externalities. This consumer benefit outweighs the potential retail price increase caused by the standard adoption.

To reiterate, application of FRAND terms may contribute to the adoption of a standard and increase the consumer surplus. Holders of ex-ante irreplaceable patents may be willing to join a standard setting agreement only if FRAND terms are employed. The use of FRAND commitment eliminates the potential incentive to increase the royalty in order to raise rival's costs and by consequence may help avoiding downstream foreclosure. Holders of ex-ante irreplaceable patents may recognize FRAND terms as a tool assuring that holders of ex-ante replaceable patents will not gain and abuse market power at their expense. Downstream producers may benefit from standard adoption, because the

presence of a common standard generates additional rent through network externalities and part of this rent may be extracted by the downstream producers. The consumer may also benefit from standard adoption in presence of FRAND terms, as the potential harm caused by the price increase may be outweighed by network externalities.

The existing literature have separately analyze standard adoption and FRAND terms. Some authors focus on pricing decisions in the context of standard setting agreements without FRAND terms and do not analyze the impact of standard setting agreements on standard adoption (see for example Schmidt, 2008, and Schmalensee, 2009). Others provide an economic interpretation of FRAND terms (see for example Layne-Farrar et al., 2007, and Layne-Farrar, 2010).

Tarantino (2010) addresses a question that is the closest to the focus of the present paper. He shows that the standard adoption may be possible without FRAND terms. In particular, he proposes a model in which FRAND terms are absent and where downstream producers decide whether to adopt a standard or not. In the proposed model, the holder of the ex-ante replaceable patent that is included in the standard is not vertically integrated with the downstream producer. It thus does not have incentives to increase its royalty to such a level that the downstream producer holding the competing patent would be eliminated from the market. In the present paper, the standard adoption depends on the incentives of patent holders to join a standard setting agreement. Here, the holder of the ex-ante replaceable patent is vertically integrated with the downstream producer and thus wishes to raise rival's cost to such a level that it would be forced to leave the market. This has a negative impact on profits generated by the holder of the other patent included in the standard. Under such circumstances, the standard setting agreement is not incentive compatible. All in all, the present paper argues that FRAND terms may be a necessary condition for standard adoption, while Tarantino (2010) shows the standard adoption may be possible without FRAND terms. The difference in the conclusions is explained by different assumptions concerning the vertical integration of the ex-ante replaceable patent included in the standard.

This article is structured as follows. The next section proposes a theoretical model including two specifications: (1) patent pools with FRAND and (2) patent pools without FRAND. Section 3 presents the results in the presence of the FRAND commitment. Section 4 explains what happens in the absence of the FRAND commitment. Finally, the last section concludes.

2 Model

Suppose that there are three patent holders (holder of patent 1, holder of patent 2 and holder of patent 3). Technologies protected by patent 1 and patent 2 are replaceable, that is one may be used in place of another without causing any direct harm. Technology protected by patent 3 is irreplaceable, meaning that there is no alternative technology that could be used in its place. Each patent holder i ($i = 1, 2, 3$) offers its technology for a licensing fee w_i. This licensing

fee is paid for each unit sold of the final good using the licensed technology.

There are two downstream producers producing goods using upstream technologies. Each downstream producer may produce a good using technology 1 combining patent 1 and patent 3 or technology 2 combining patent 2 and patent 3.

Let q_{jk} denote the quantity of the good sold by producer j ($j = 1, 2$) using technology k ($k = 1, 2$).

Suppose that downstream producer 1 is vertically integrated with holder of patent 1 and downstream producer 2 is vertically integrated with holder of patent 2.

The goods produced by downstream producers generate network externalities. The number of consumers using a given technology increases hence the willingness to pay for a good using the same technology. If one technological standard is adopted, that is if both downstream producers sell products using the same technology k, the profit of producer j is given by:

$$\Pi_{jk} = [1 + \alpha q_{jk} + \alpha q_{-jk} - q_{jk} - q_{-jk} - w_{jk}]q_{jk} + v_{jk}q_{-jk}$$

where: $\alpha \in (0, 1)$ measures the level of network externalities, q_{jk} is the quantity sold by producer j, q_{-jk} is the quantity sold by its competitor, w_{jk} is the sum of royalties paid for technology k by downstream producer j ($w_{jk} = w_3$ if $k = j$ and $w_{jk} = w_{-j} + w_3$ otherwise) and v_{jk} is the royalty that downstream producer j receives in compensation for licensing its technology to the competitor ($v_{jk} = w_j$ if $k = j$ and $v_{jk} = 0$ otherwise).

If the downstream producers offer goods using different technologies, the profit of producer j is given by:

$$\Pi_{jk} = [1 + \alpha q_{jk} - \alpha q_{-j-k} - q_{jk} - q_{-j-k} - w_3]q_{jk}$$

where: $\alpha \in (0, 1)$ measures the level of network externalities, q_{jk} is the quantity sold by producer j, q_{-j-k} is the quantity sold by its competitor and w_3 is the royalty paid by downstream producer j to holder of patent 3.

Patent holders may enter into a standard setting agreement. Patents used in the standard are licensed as a bundle and may not be licensed separately. In other words, after the standard adoption the adopted standard is the unique available technology. This is a simplifying assumption corresponding to the antitrust concerns raised by the competition authorities and discussed in the economic literature (see for example Farrell, 2007). The technological solutions not used in adopted standards may be sometimes forced to leave the market because of consumer lock-in, high switching costs or compatibility problems. This paper does not aim at explaining the phenomenon of disappearance of alternative technological solutions not used in the standard, but for simplicity assumes that it takes place.

There two alternative specifications of the model:

Specification 1 (with FRAND terms)

- **Stage 1**: Holder of patent 3 decides whether to start standard setting negotiations or not.

- **Stage 2**: If the holder of patent 3 did not enter in standard setting negotiations, each downstream producer j adopts technology $k = j$. Otherwise, holders of patent 1 and patent 2 simultaneously announce their royalties. The one that proposes the lowest royalty enters into a standard setting agreement with holder of patent 3. In case of a tie, one of them is chosen randomly. If the standard setting agreement is signed, the adopted standard k becomes the only available technology.

- **Stage 3**: Holder of patent 3 sets its royalty.

- **Stage 4**: Each downstream decides on the quantity offered for sales (q_{jk}) basing on the available technology k ($k = j$, if there is no standard and $k = \tilde{k}$ if standard $\tilde{k}$ has been adopted). For each unit of the good sold, it pays the royalty w_3 to holder of patent 3. Additionally, if there is a standard using the technology protected by the patent of its competitor, it pays the royalty w_{-j} on each unit sold to its competitor. The price for a good using technology k is given by $p_k = 1+\alpha q_{jk}+\alpha q_{-jk}-q_{jk}-q_{-jk}$, if the standard is adopted in stage 1, and by $p_k = 1+\alpha q_{jk}-\alpha q_{-j-k}-q_{jk}-q_{-j-k}$, otherwise.

Specification 2 (without FRAND terms)

- **Stage 1**: Holder of patent 3 decides whether to enter into a standard setting agreement or not. If it decides to do so, it indicates with which other patent holder the agreement is reached. If the standard setting agreement is signed, the adopted standard k becomes the only available technology.

- **Stage 2**: If there is a standard setting agreement, holder of patents for technologies included in the standard simultaneously announce their royalties. Otherwise, only holder of patent 3 sets its royalty.

- **Stage 3**: This stage is the same as stage 4 in specification 1 (with FRAND terms).

The first specification (with FRAND commitment) corresponds to the economic interpretation of FRAND terms according to which FRAND terms are the terms that would have been negotiated ex-ante. Here, if a standard setting agreement is reached, the holder of ex-ante replaceable patent included in the standard sets its royalty before the competing patent disappears from the market. This assumption is introduced in order to explicitly verify what royalties the holders of ex-ante replaceable patents would set before their inclusion in the standard.

The second specification (without FRAND terms) represent standard setting agreement without FRAND terms. Here, the royalty for ex-ante replaceable patent included in the standard is set after the disappearance of its competitor. The standard setting agreement is hence incomplete in the sense that it does not specify the royalties. This setting potentially increases the market power of the holder of ex-ante replaceable patent included in the standard and may lead to the hold-up problem.

In both specifications, the holder of ex-ante irreplaceable patent always sets its royalty after the potential disappearance of the patent not included in the standard. This assumption is made for clarity purposes and does not affect the results. The disappearance of one of the ex-ante competing patents does not change the incentives of the holder of the complementary patent, so its behavior would not change it if it had to set its royalty in stage 1.

The willingness of the holder of ex-ante replaceable patent to participate in a standard setting agreement is not explicitly modeled for simplicity. This assumption does not affect the results. As will be shown, by participating in the standard setting agreement, the holder of the ex-ante replaceable patent always increases its profit and therefore it would be always willing to join such an agreement.

3 Results - Specification 1 (with FRAND terms)

The model is solved by the backward induction.

Stage 4 (quantity setting)

In stage 4, downstream firms set their quantities depending on the resulting market prices and the royalties they need to pay for the adopted technologies. There are two possible states of the world: (1) the standard was adopted and (2) the standard was not adopted.

The standard is adopted

If the standard is adopted, consumers benefit from network externalities and are therefore willing to pay more for the final good than in the absence of the standard. When setting their volumes, downstream producers take into account these network externalities as wells as downstream prices and licensing costs.

If technology 1 is adopted as the standard, profits of downstream firms are given by:

$$\Pi_{11} = [1 + \alpha q_{11} + \alpha q_{21} - q_{11} - q_{21} - w_3]q_{11} + w_1 q_{21}$$

$$\Pi_{21} = [1 + \alpha q_{11} + \alpha q_{21} - q_{11} - q_{21} - w_3 - w_1]q_{21} - w_1 q_{21}$$

The optimal volumes maximizing these profit functions are:

$$q_{11} = \frac{1 + w_1 - w_3}{3(1 - \alpha)} \tag{3.1}$$

$$q_{21} = \frac{1 - 2w_1 - w_3}{3(1 - \alpha)} \tag{3.2}$$

Give these optimal volumes, the final price becomes:

$$p_1 = \frac{1 + w_1 + 2w_3}{3} \tag{3.3}$$

By symmetry, if technology 2 is adopted as the standard in stage 1, the optimal quantities and the final prices may be written as:

$$q_{12} = \frac{1 - 2w_2 - w_3}{3(1 - \alpha)} \tag{3.4}$$

$$q_{22} = \frac{1 + w_2 - w_3}{3(1 - \alpha)} \tag{3.5}$$

$$p_2 = \frac{1 + w_2 + 2w_3}{3} \tag{3.6}$$

The comparison of the above volumes shows that the optimal volume of the downstream producer holding patent used in the standard is at least as high that the optimal volume of the other downstream producer ($q_{11} \geq q_{21}$ and $q_{22} \geq q_{12}$). This is because the downstream producer j holding the patent used in the standard faces licensing costs (w_3) that are at least as low as those of its competitor ($w_3 + w_{-j}$).

The final price is increasing in royalties ($\frac{\partial p_k}{\partial w_{jk}} > 0$), as royalties constitute marginal costs that are fully passed on to the consumers.

The standard is not adopted

If the standard is not adopted, downstream producers use different technologies. Presence of two alternative technologies implies that consumers of the good offered by one producer generate positive synergies on each other. Therefore, consumer willingness to pay depends on the relative size of the consumer pool of one product vs. the consumer pool of the other product. In other words, consumers are willing to pay more for a given product for every new consumer gained by the chosen producer and decrease their willingness to pay for every consumer lost to the competitor. The profit of downstream producers are given by:

$$\Pi_{11} = [1 + \alpha q_{11} - \alpha q_{22} - q_{11} - q_{22} - w_3]q_{11}$$

$$\Pi_{22} = [1 - \alpha q_{11} + \alpha q_{22} - q_{11} - q_{22} - w_3]q_{22}$$

The above profit functions yield the following optimal volumes:

$$q_{11} = q_{22} = \frac{1 - w_3}{3 - \alpha} \tag{3.7}$$

In the absence of standard, the optimal quantities are identical. This is a natural consequence of the fact that downstream producers face identical marginal costs (w_3).

Given these optimal volumes, the resulting price is:

$$p_1 = p_2 = 1 - \frac{2(1 - w_3)}{3 - \alpha} \tag{3.8}$$

The resulting price is increasing in the royalty (w_3), implying that the licensing costs are passed on to the consumers.

Stage 3 (optimal royalty for ex-ante irreplaceable patent)

In stage 3, the holder of patent 3 sets its royalty. There are two potential scenarios: (1) the standard was adopted or (2) the standard was not adopted.

The standard is adopted

If the standard is adopted, the holder of patent 3 sets an optimal royalty maximizing its profit given the optimal volumes derived for stage 4. If technology 1 is adopted, the profit of the holder of patent 3 is given by its royalty multiplied by optimal volumes given by (3.1) and (3.2):

$$\Pi_3 = \frac{w_3(2 - w_1 - 2w_3)}{3(1 - \alpha)}$$

The optimal royalty maximizing the above profit function is given by:

$$w_3 = \frac{2 - w_1}{4} \tag{3.9}$$

Substituting (3.9) into (3.1)-(3.3) yields the optimal quantities and the resulting price:

$$q_{11} = \frac{2 + 5w_1}{12(1 - \alpha)} \tag{3.10}$$

$$q_{21} = \frac{2 - 7w_1}{12(1 - \alpha)} \tag{3.11}$$

$$p_1 = \frac{4 + w_1}{6} \tag{3.12}$$

By symmetry, if technology 2 is adopted as the standard, the following royalties, quantities and price arise:

$$w_3 = \frac{2 - w_2}{4} \tag{3.13}$$

$$q_{12} = \frac{2 - 7w_2}{12(1 - \alpha)} \tag{3.14}$$

$$q_{22} = \frac{2 + 5w_2}{12(1 - \alpha)} \tag{3.15}$$

$$p_2 = \frac{4 + w_2}{6} \tag{3.16}$$

The comparison of (3.10) with (3.11) and (3.15) with (3.14) indicates that as long as the downstream producer j holding the patent used in the standard charges a positive royalty ($w_j > 0$), it will produce more than its concurrent ($q_{jj} > q_{-jj}$). Furthermore, given (3.12) and (3.16), the price is increasing in the level royalty for the ex-ante replaceable patent included in the standard. In other words, the level of the royalty for the ex-ante replaceable patent included in the standard has a positive impact on the profit of its holder and decreases the consumer surplus.

The standard is not adopted

In the absence of the standard, the profit function of holder of patent 3 depends on optimal volumes (3.7) and its royalty. In particular, it may be written as:

$$\Pi_3 = \frac{2w_3(1 - w_3)}{3 - \alpha}$$

The optimal royalty maximizing the above profit function is given by:

$$w_3 = \frac{1}{2} \tag{3.17}$$

The optimal quantities (3.7), prices (3.8) and profits of downstream producers become:

$$q_{11} = q_{22} = \frac{1}{2(3 - \alpha)} \tag{3.18}$$

$$p_1 = p_2 = \frac{2 - \alpha}{3 - \alpha} \tag{3.19}$$

$$\Pi_{11} = \Pi_{22} = \frac{1 - \alpha}{4(1 - \alpha)^2} \tag{3.20}$$

The optimal quantities (3.18) are increasing in α, meaning that downstream producers are willing to increase their quantities if network externalities become more important. This is because network externalities positively affect the price. The higher network externalities, the more consumers are willing to pay for a given good. The downstream producer may hence be willing to increase its volume in order to extract part of the rent generated by network externalities.

The effect of network externalities on prices depend on the value of α. It is positive if $\alpha > \frac{1}{2}$ (as $\frac{\partial p_1}{\partial \alpha} = \frac{\partial p_2}{\partial \alpha} = -\frac{1-2\alpha}{(3-\alpha)^2} > 0$ for $\alpha > \frac{1}{2}$) and negative if $\alpha < \frac{1}{2}$.

Stage 2 (standard setting negotiations and determining royalties for ex-ante replaceable patents)

In stage 2, technologies are adopted. If standard setting negotiations do not start in stage 1, downstream producers rely on technologies using their respective patents. If standard negotiations start in stage 1, holders of patents 1 and 2 are asked to propose their royalties. Given that the one which proposes higher royalty will not be included in the standard and will be hence excluded from the market, patent holders are willing to engage in a bidding war. The competition between those two patent holders will drive their royalties to 0.

Lemma 1. *In the presence of FRAND commitment, holders of ex-ante replaceable patents will demand zero royalties*

Proof. Suppose that there exist an equilibrium in which holders of ex-ante replaceable patents set positive royalties $\hat{w}_1$ and $\hat{w}_2$. Without loss of generality, suppose that $\hat{w}_1 > \hat{w}_2 > 0$. Then, by decreasing its royalty to the level of $\hat{w}_2 - \varepsilon$, the holder of patent 1 would assure that its patent is included in the standard. Then, given (3.10) and (3.14), it would increase its volume from $\frac{2-7\hat{w}_2}{12(1-\alpha)}$ to $\frac{2+5(\hat{w}_2+\varepsilon)}{12(1-\alpha)}$ and its income generated on royalties from 0 to $\frac{(\hat{w}_2+\varepsilon)(2-7(\hat{w}_2-\varepsilon))}{12(1-\alpha)}$. In the same time, the price (given by (3.12) or (3.16)) would decrease from $\frac{4+\hat{w}_2}{6}$ to $\frac{4+\hat{w}_2-\varepsilon}{6}$. This insignificant price decrease would be hence compensated by the increased volume and increased income from royalties. Therefore, the holder of patent 1 would always have incentives to undercut the holder of patent 2 by a very small amount as long as $\hat{w}_1 > \hat{w}_2 > 0$. If $\hat{w}_1 = \hat{w}_2 > 0$, by setting its royalty at $\hat{w}_2 - \varepsilon$, the holder of patent 1 would increase its expected volume from $\frac{1}{2}\left(\frac{2-7\hat{w}_2}{12(1-\alpha)} + \frac{2+5\hat{w}_2}{12(1-\alpha)}\right)$ to $\frac{2+5(\hat{w}_2+\varepsilon)}{12(1-\alpha)}$. In the same, its income from royalties would increase from $\frac{\hat{w}_2(2-7\hat{w}_2)}{24(1-\alpha)}$ to $\frac{(\hat{w}_2+\varepsilon)(2-7(\hat{w}_2+\varepsilon))}{12(1-\alpha)}$, while the retail price would decline from $\frac{4+\hat{w}_2}{6}$ to $\frac{4+\hat{w}_2-\varepsilon}{6}$. Overall, its profit would increase. Hence, it will always have incentives to undercut the holder of patent 2 by a very small amount as long as $\hat{w}_1 \geq \hat{w}_2 > 0$. A contradiction. □

Given that the royalties charged by holders of ex-ante replaceable patents will be set at 0, the optimal volumes ((3.10), (3.11), (3.14) and (3.15)), royalties ((3.9) and (3.13)), prices ((3.12) and (3.16)) and profits of downstream producers in the presence of standard become:

$$q_{11} = q_{21} = q_{12} = q_{22} = \frac{1}{6(1-\alpha)} \tag{3.21}$$

$$w_1 = w_2 = 0 \tag{3.22}$$

$$w_3 = \frac{1}{2} \tag{3.23}$$

$$p_1 = p_2 = \frac{2}{3} \tag{3.24}$$

$$\Pi_{11} = \Pi_{21} = \Pi_{12} = \Pi_{22} = \frac{1}{36(1-\alpha)} \tag{3.25}$$

Interestingly, the price in the presence of the standard (3.24) would be higher than the one charged in the absence of the standard (3.19). This is because in presence of the standard, consumers benefit from higher network externalities and downstream producers extract part of this rent.

Intuitively, the royalty charged by the ex-ante irreplaceable patent (3.23) is the same as it would charge in the absence of the standard (3.17). This is because patent 3 is an essential asset of every single available technology and the standard adoption does not affect its market power.

As the ex-ante competition drives the royalty for ex-ante replaceable patent down to 0, downstream producers sell identical volumes (3.21) of the final good. This may be explained by the fact that given that the holder of the ex-ante replaceable patent charges zero royalty, downstream producers face identical costs and are therefore symmetric.

Finally, as (3.25) is higher than (3.20), it is always in interest of the holder of the ex-ante replaceable patent to join the standard setting agreement. This is because standard adoption generates more network externalities for the final consumers and downstream producers are able to capture a part of this additional rent.

Stage 1 (initiative to undertake standard setting negotiations)

In stage 1, the holder of patent 3 decides whether to start standard setting negotiations or not. No matter whether it starts the negotiations or not, it will set exactly the same royalty as (3.23) is equal to (3.17). Therefore, the decision whether to engage into standard setting negotiations depend on the expected downstream volumes. Given (3.21), the standard adoption will yield the following downstream volume:

$$\frac{1}{3(1-\alpha)} \tag{3.26}$$

Given (3.18), the absence of the standard adoption will imply the following volume:

$$\frac{1}{3-\alpha} \tag{3.27}$$

As (3.26) is higher than (3.27), the holder of patent 3 will always prefer to enter into standard setting agreement.

All in all, the holder of patent 3 will enter into standard setting agreement with one of the holders of the ex-ante replaceable patent. Lemma 1 implies that the ex-ante replaceable patent will be licensed for 0. What's more, (3.21)-(3.24) imply that the ex-ante irreplaceable patent will be licensed for a royalty of $\frac{1}{2}$,

each downstream producer will offer the quantity of $\frac{1}{6(1-\alpha)}$ and the final price will be given by $\frac{2}{3}$.

Theorem 2. *In presence of FRAND, there exists a unique type of subgame perfect equilibrium in pure strategies. In this equilibrium, a standard setting agreement is reached between holder of patent 3 and one of the holders of ex-ante replaceable patents. The ex-ante irreplaceable patent sets a royalty of* $\frac{1}{2}$. *The other patent included in the standard is licensed for free. Each downstream producer sells* $\frac{1}{6(1-\alpha)}$ *units of the downstream good. The final price is given by* $\frac{2}{3}$.

Proof. In the text. □

4 Results - specification 2 (without FRAND terms)

Specification 2 studies the standard adoption in absence of FRAND terms and includes one stage less than specification 1. Stage 3 of specification 2 corresponds to stage 4 of specification 1 and is the stage in which downstream producers set their volumes. In stage 2 of specification 2 royalties are set. In stage 1, holder of patent 3 decides whether to sign a standard setting agreement or not. If it decides to do so, its role is limited to indicating the other party with which the agreement is signed and it may not force this party to commit to any level of future royalties.

Specification 2 does not include FRAND terms and thus gives more market power to the holder of ex-ante replaceable patent included in the standard than specification 1 (with FRAND terms). Here, the holder of the ex-ante replaceable patent included in the standard sets its royalty after the competing patent disappears from the market. Facing no competition, it is free to increase its royalty. In specification 1, the holder of the ex-ante replaceable patent included in the standard set its royalty before the exclusion of the competing patent and therefore faced stronger competitive pressure on its royalties.

Specification 2 introduces potential hold-up problem. As the holder of the ex-ante replaceable patent included in the standard sets it royalty after the market foreclosure of the competing patent, it gains additional market power and may potentially abuse it. This potential abuse of supplementary market power is a typical hold-up problem.

The absence of FRAND terms in specification 2 introduces a possibility for downstream market foreclosure. As the holder of the ex-ante replaceable patent included in the standard is vertically integrated with the downstream producer, it has incentives to increase its royalty in order to raise rival's costs. In specification 1, the holder of the ex-ante replaceable patent also had incentives to raise rival's was cost, but in the same time faced competitive pressure from the competing patent and was therefore unable to increase its royalty without risking of being excluded from the standard. Here, the holder of the ex-ante replaceable patent is given market power to raise its royalty without loosing the

standard setting agreement. It may even set the royalty at such a high level that its competitor will be driven out of the market.

The model is solved by backward induction.

Stage 3

The standard is adopted

No downstream market foreclosure

If there is no downstream market foreclosure (that is royalties for patents included in the standard are at such a level that optimal volumes are nonnegative), the optimal quantities and prices are the same as in stage 4 of specification 1 ((3.1)-(3.6)):

$$q_{11} = \frac{1 + w_1 - w_3}{3(1-\alpha)} \tag{4.1}$$

$$q_{21} = \frac{1 - 2w_1 - w_3}{3(1-\alpha)} \tag{4.2}$$

$$q_{12} = \frac{1 - 2w_2 - w_3}{3(1-\alpha)} \tag{4.3}$$

$$q_{22} = \frac{1 + w_2 - w_3}{3(1-\alpha)} \tag{4.4}$$

$$p_1 = \frac{1 + w_1 + 2w_3}{3} \tag{4.5}$$

$$p_2 = \frac{1 + w_2 + 2w_3}{3} \tag{4.6}$$

Downstream market foreclosure

It is possible that royalties for patents included in the standard are at such a level that it is not profitable for the downstream producer which does not hold the patent included in the standard to sell any product. For example, if technology 1 is adopted as the standard and w_1 and w_3 are so high that q_{21} given by (4.2) becomes negative, it is in interest of seller 2 not to sell any good. The best reply of the holder of patent 1 to such a market foreclosure is then to set a volume maximizing its profit:

$$\Pi_{11} = (1 - (1-\alpha)q_{11} - w_3)q_{11}$$

The optimal volume maximizing the above profit function is given by:

$$q_{11} = \frac{1 - w_3}{2(1-\alpha)} \tag{4.7}$$

The resulting price is:

$$p_1 = \frac{1 + w_3}{2} \tag{4.8}$$

The standard is not adopted

If the standard is not adopted, stage 3 of specification 2 becomes equivalent to stage 4 of specification 1. Therefore, given (3.7) and (3.8), the following optimal volumes and prices arise:

$$q_{11} = q_{22} = \frac{1 - w_3}{3 - \alpha} \tag{4.9}$$

$$p_1 = p_2 = 1 - \frac{2(1 - w_3)}{3 - \alpha} \tag{4.10}$$

Stage 2

In stage 2 of specification 2, royalties are set. There are two possible states of the world: (1) the standard is adopted and (2) the standard is not adopted.

The standard is adopted

Without loss of generality suppose that the standard is adopted between holder of patent 1 and holder of patent 3. Then, given (4.1), (4.2), (4.5), (4.7) and (4.8), holder of patent 1 chooses the royalty w_1 that maximizes its profit:

$$\Pi_{11} = \begin{cases} \frac{1+w_1-w_3}{3(1-\alpha)} \cdot \frac{1+w_1+2w_3}{3} + \frac{1-2w_1-w_3}{3(1-\alpha)} \cdot w_1 & \text{if } \frac{1-2w_1-w_3}{3(1-\alpha)} > 0 \\ \frac{1-w_3}{2(1-\alpha)} \cdot \frac{1+w_3}{2} & \text{otherwise} \end{cases}$$

where the first line corresponds to the situation in which producer 2 is not excluded from the downstream market and the second line presents the profit of producer 1 when producer 2 is excluded from the downstream market.

In the same time, holder of patent 3, chooses the royalty w_3 that maximizes its profit that is determined by (4.1), (4.2) and (4.7):

$$\Pi_3 = \begin{cases} \frac{2-w_1-2w_3}{3(1-\alpha)} \cdot w_3 & \text{if } \frac{1-2w_1-w_3}{3(1-\alpha)} > 0 \\ \frac{1-w_3}{2(1-\alpha)} \cdot w_3 & \text{otherwise} \end{cases}$$

where the first line corresponds to the situation in which producer 2 is not excluded from the downstream market and the second line is related to the situation in which producer 2 is excluded from the downstream market.

The optimal royalties maximizing the above profit functions are:

$$w_1 \geq \frac{8}{19} \tag{4.11}$$

$$w_3 = \frac{1}{2} \tag{4.12}$$

(4.11) implies that the volume of producer 2 given by (4.2) would be negative. This implies that producer 2 is excluded from the market. Then, substituting (4.11) and (4.12) into (4.7) and (4.8) gives optimal volumes and prices:

$$q_{11} = \frac{1}{4(1-\alpha)} \tag{4.13}$$

$$q_{21} = 0 \tag{4.14}$$

$$p_1 = \frac{3}{4}$$

The resulting profit of the downstream producers are:

$$\Pi_{11} = \frac{1}{16(1-\alpha)} \tag{4.15}$$

$$\Pi_{21} = 0 \tag{4.16}$$

By symmetry, if technology 2 is adopted as the standard:

$$w_2 \geq \frac{8}{19} \tag{4.17}$$

$$w_3 = \frac{1}{2} \tag{4.18}$$

$$q_{12} = 0 \tag{4.19}$$

$$q_{22} = \frac{1}{4(1-\alpha)} \tag{4.20}$$

$$p_2 = \frac{3}{4} \tag{4.21}$$

$$\Pi_{12} = 0 \tag{4.22}$$

$$\Pi_{22} = \frac{1}{16(1-\alpha)} \tag{4.23}$$

The royalties set by the holder of the ex-ante replaceable patent are so high ($w_j \geq \frac{8}{19}$) that its competitor is excluded from the downstream market ($q_{21} = 0$ and $q_{12} = 0$). In other words, in the absence of FRAND commitment,the vertically integrated holder of the ex-ante replaceable patent included in the standard has incentives to increase its royalty in order to raise rival's costs and exclude it from the downstream market.

The standard is not adopted

Given (4.9), in the absence of a standard, the holder of patent 3 sets a royalty r_3 that maximizes its profit:

$$\frac{2w_3(1-w_3)}{3-\alpha}$$

The optimal royalty for patent 3 is given by:

$$w_3 = \frac{1}{2} \tag{4.24}$$

Substituting (4.24) in (4.9) and (4.10) returns the downstream volumes, prices and profits:

$$q_{11} = q_{22} = \frac{1}{2(3-\alpha)} \tag{4.25}$$

$$p_1 = p_2 = \frac{2-\alpha}{3-\alpha} \tag{4.26}$$

$$\Pi_{11} = \Pi_{22} = \frac{1-\alpha}{4(3-\alpha)^2} \tag{4.27}$$

The final price under standard adoption (4.21) is higher than the final price when two alternative technologies co-exist (4.26). This happens for two reasons. First, the standard adoption implies higher consumer benefits from network externalities allowing for a price increase. Second, if a standard is adopted without FRAND commitment, the holder of the ex-ante replaceable patent included in the standard sets its royalty at a very high level in order to exclude its competitor from the downstream market. Given this downstream market foreclosure, it benefits from more market power and therefore further increases the price.

The royalty charged for the ex-ante irreplaceable patent (w_3) is the same in the presence of the standard as in the absence of the standard, as (4.12) is equal to (4.24). This is because the irreplaceable patent is an essential asset in both cases, so its value is not affected by the standard adoption.

In the absence of the standard, the profit of the downstream producer (4.27) is lower than the profit of each downstream producer holding the patent included in the standard given by (4.15) or (4.23). Hence, it is always in the interest of the holder of the ex-ante replaceable patent to join the standard setting agreement. This happens for two reasons. First, standard adoption generates more network externalities and the holder of the ex-ante irreplaceable patent included in the standard captures a part of the generated rent. Second, having its patent included in the standard allows softening downstream competition and therefore generate higher profits for the downstream producer vertically integrated with the holder of the ex-ante irreplaceable patent included in the standard.

Stage 1

In stage 1, the holder of patent 3 decides whether to enter into the standard setting agreement or not. Given (4.12)-(4.14) and (4.18)-(4.20), if it decides to enter into a standard setting agreement, its profit will be given by:

$$\Pi_3 = \frac{1}{8(1-\alpha)} \tag{4.28}$$

Given (4.24)-(4.25), if it does not enter into a standard setting agreement, its profit will be given by:

$$\Pi_3 = \frac{1}{2(3-\alpha)} \tag{4.29}$$

Since (4.28) is higher that (4.29) as long as $\alpha > \frac{1}{3}$, a standard setting agreement will take place only if network externalities are sufficiently high. What's more, given (4.14) and (4.19), in this equilibrium, the downstream producer that does not hold the patent included in the standard will be foreclosed from the downstream market. By consequence, the remaining downstream producer will fully exercise its monopolistic power.

In the presence of strong network externalities, the holder of the ex-ante irreplaceable patent will benefit from the standard adoption despite the downstream market foreclosure. The standard adoption does not change the royalty demanded by the holder of the ex-ante irreplaceable patent (as (4.12) is equal to (4.18)), but affects the downstream volume. If network externalities are strong, the standard adoption will lead to higher downstream volume than the volume that would be set if two alternative technologies co-existed. There may hence exist a subgame perfect equilibrium with a standard setting agreement for sufficiently strong network externalities.

Theorem 3. *In the absence of FRAND commitment, if network externalities are sufficiently high ($\alpha > \frac{1}{3}$), there is a unique type of subgame perfect equilibria in pure strategies. In this equilibrium, the holder of the ex-ante irreplaceable patent enters into the standard setting agreement with one of the holders of ex-ante replaceable patents and sets a royalty of $\frac{1}{2}$.The holder of the ex-ante replaceable patent included in the standard sets a royalty of at least $\frac{8}{19}$. The downstream producer holding the patent included in the standard monopolizes the market and offers the quantity of $\frac{1}{4(1-\alpha)}$. The other producer is foreclosed from the market. The final price is given by $\frac{3}{4}$.*

Proof. In the text. □

As compared to the equilibrium identified for specification 1 with FRAND terms (presented by theorem 2), the above presented equilibrium leads to higher retail price ($\frac{3}{4}$ vs.$\frac{2}{3}$), lower quantity ($\frac{1}{4(1-\alpha)}$ vs. $\frac{1}{3(1-\alpha)}$) and higher royalty for the ex-ante replaceable patent ($\frac{8}{19}$ vs. 0). The holder of the ex-ante irreplaceable patent sets the same royalty of $\frac{1}{2}$ and earns lower profit ($\frac{1}{8(1-\alpha)}$ vs. $\frac{1}{6(1-\alpha)}$). The profit of the downstream producer holding the patent included in the standard

increases from $\frac{1}{36(1-\alpha)}$ to $\frac{1}{16(1-\alpha)}$. The profit of the other downstream producer decreases from $\frac{1}{36(1-\alpha)}$ to 0.

Corollary 4. *If network externalities are sufficiently strong ($\alpha > \frac{1}{3}$), FRAND terms increase the consumer welfare and the profit of holder of the ex-ante irreplaceable patent. The profit of the downstream producer holding the patent included in the standard decreases, while the profit of the other downstream producer increases.*

If network externalities are sufficiently low ($\alpha < \frac{1}{3}$), (4.29) is higher than (4.28) and hence a standard setting agreement is not signed in the absence of FRAND terms. This is because low network externalities imply that after the market foreclosure of its competitor, the downstream producer adopting the standard will set lower quantity than two downstream producers would set if two alternative technologies were adopted. As the holder of patent 3 will maintain the same royalty ($\frac{1}{2}$) in both cases, the standard adoption would imply a decline in its profit. Then, it would not sign a standard setting agreement. In other words, a standard setting agreement is not incentive compatible in the absence of FRAND terms if network externalities are low ($\alpha < \frac{1}{3}$).

Theorem 5. *In the absence of FRAND commitment, if network externalities are sufficiently low ($\alpha < \frac{1}{3}$), there is a unique type of subgame perfect equilibria in pure strategies. In this equilibrium, the holder of ex-ante irreplaceable patent does not enter into the standard setting agreement and sets a royalty equal to $\frac{1}{2}$. Each downstream producer offers the quantity $\frac{1}{2(3-\alpha)}$. The final price is $\frac{2-\alpha}{3-\alpha}$.*

Proof. In the text. □

As compared to the equilibrium identified for specification 1 with FRAND terms (presented by theorem 2), equilibrium presented in theorem 5 leads to lower quantity ($\frac{1}{3(1-\alpha)}$ vs. $\frac{1}{(3-\alpha)}$) and lower prices ($\frac{2}{3}$ vs. $\frac{2-\alpha}{3-\alpha}$). The overall effect on the consumer is negative, as the consumer surplus in the presence of FRAND terms ($\frac{1}{9(1-\alpha)}$) is higher than the consumer surplus in the absence of FRAND ($\frac{2-\alpha}{2(3-\alpha)^2}$). What's more, in presence of FRAND terms, the profit of the holder of the ex-ante irreplaceable patent increases from $\frac{1}{2(3-\alpha)}$ to $\frac{1}{6(1-\alpha)}$ and the profit of each downstream producer increases from $\frac{1-\alpha}{4(3-\alpha)^2}$ to $\frac{3}{12(1-\alpha)}$.

Corollary 6. *If network externalities are sufficiently weak ($\alpha < \frac{1}{3}$), FRAND terms increase the consumer welfare and profits of all the patent holders.*

FRAND terms may be necessary for standard adoption and beneficiary for consumers. As theorem 2 shows, in the presence of FRAND terms, the standard is adopted. As theorem 5 indicates, the standard may not be adopted in the absence of FRAND terms. FRAND terms may be thus a necessary condition for standard adoption. What's more, as corollary 6 demonstrates, standard adoption relying on FRAND terms is beneficiary for the consumers.

Theorem 7. *If network externalities are sufficiently weak ($\alpha < \frac{1}{3}$), FRAND terms are a necessary condition for standard adoption and lead to higher consumer surplus.*

Proof. In the text. □

To conclude, the holder of the ex-ante irreplaceable patent may not be willing to join a standard setting agreement without FRAND terms. The potential unwillingness of the holder of the ex-ante irreplaceable to sign a standard setting agreement in absence of FRAND terms is related to the potential market power abuse of the holder of the ex-ante replaceable patent included in the standard. The absence of FRAND terms gives the holder of the ex-ante replaceable patent included in the standard a possibility to increase its royalty to such a level that its downstream competitor will be foreclosed from the market. Such a downstream market foreclosure may negatively affect the profit of the holder of the ex-ante irreplaceable patent. The holder of the ex-ante irreplaceable patent may then prefer to contract directly with the downstream producers rather than sign a standard setting agreement.

FRAND terms may be necessary for standard adoption. In the absence of FRAND terms, the holder of the ex-ante irreplaceable patent may be not willing to sign a standard setting agreements fearing potential abuses of the holder of the ex-ante replaceable patent included in the standard. Its motivation changes if FRAND terms are adopted. FRAND terms eliminate potential abuses of the holders of ex-ante replaceable patents and therefore increase the profits of the holder of the ex-ante irreplaceable patent. Being secured by FRAND terms, the holder of the ex-ante irreplaceable patent may be more willing to enter into the standard setting agreement.

FRAND terms may not only stimulate the standard adoption, but may be also beneficial for the consumers. By stimulating standard adoption, they may allow final consumers to benefit from additional network externalities. Even if the downstream producers capture part of this rent by increasing their prices, the consumers may be still better off in the presence of the standard relying on FRAND terms.

5 Conclusion

Standard setting agreements may lead to the hold-up problem. Standard adoption may lead to the exclusion of the technological solutions constituting alternatives to the solutions used in the standard. Once these alternative technological solutions disappear from the market, the holders of patents used in the standard may abuse their increased market power. This potential abuse of the supplementary market power gained after the standard adoption is often referred as to the hold-up problem.

Standard setting agreements may also result in the downstream foreclosure. If the holder of the patent included in the standard is vertically integrated with the downstream producer, it may have incentives to increase its royalty in order

to raise rival's cost. That may soften downstream competition. In the extreme case, some downstream producers may be excluded from the market.

The present paper shows that FRAND terms are a practical solution to the potential hold-up problem and downstream foreclosure. By committing patent holders to behave ex-post as if they were still facing their competitors that were present ex-ante, they eliminate the possibility to exploit the increased market power after the standard adoption and thus remove the potential hold-up problem and downstream foreclosure. More specifically, they force holders of ex-ante replaceable patents to charge "reasonable" royalties so that downstream producers face "reasonable" licensing costs and are not forced to leave the market.

The present paper argues that the FRAND commitment may have another beneficial effect: it may stimulate the standard adoption. Holders of irreplaceable patents may be willing to join a standard setting agreement only if it includes FRAND terms. In the absence of FRAND terms, holders of ex-ante replaceable patents may abuse their increased market power, which may have an adverse effect on profits earned by holders of ex-ante irreplaceable patents. Holders of ex-ante irreplaceable patents may thus not be willing to join standard setting agreements in the absence of FRAND commitment. They may prefer to contract directly with the downstream producers rather than to join a patent pool. The presence of FRAND terms may eliminate potential abuses of holders of the ex-ante replaceable patent and thus increase profits of holders of the ex-ante irreplaceable patents above the level they could achieve by contracting directly with downstream producers. In such a scenario, the standard setting agreement becomes incentive compatible. The presence of the FRAND commitment may be thus a necessary condition for the standard adoption.

The present paper also finds that the standard adoption in the presence of the FRAND commitment may be beneficial for the consumers. These beneficial effects may results from network externalities. By promoting the provision of inter-operable products, the standard adoption may increase the consumer surplus. Even though downstream producers may increase prices after the standard adoption, consumers may be better off in the presence of a standard relying on FRAND terms. This is because network externalities may outweigh potential consumer harm resulting from the price increase.

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