EX-ANTE AGREEMENTS AND FRAND COMMITMENTS IN A REPEATED GAME OF STANDARD-SETTING ORGANIZATIONS*

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Abstract. I study licensing and technology choice in standard setting. I find that there may be inefficient adoption of technologies, even when firms commit to a maximum royalty or price cap for the use of their patents. When firms interact repeatedly to develop standards, a commitment to set FRAND (fair, reasonable and non-discriminatory) royalty fees may lead to more efficient technologies and higher surplus for all parties. This result can explain why standard-setting organizations favor FRAND commitments over more structured licensing commitments –such as price caps– and why there are been relatively few cases of hold-up in practice, even though such opportunistic behavior has been a primary cause of concern for innovation economists.

Keywords: Standard Formation, Standard-Setting Organizations, Hold Up, Price Caps, FRAND Commitments, Repeated Games, Relational Contracts (JEL: O31, O34, L15, L40).

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1. Introduction

Technical standards may be subject to opportunistic behavior (hold-up) from the owners of standard-essential patents (SEPs). In an effort to avoid hold-up, many standard-setting organizations (SSOs) require participants to commit to license their patents on fair, reasonable and non-discriminatory (FRAND) terms; but these commitments may be insufficient if SSO members differ as to the level of licensing fees that they consider "fair and reasonable."

Ex ante negotiations of licensing terms –in the form of price caps– help avoid the ambiguity of FRAND commitments, but may fail to work because they increase bargaining costs and slow down the standard-setting process.[1]

I study a model of licensing and technology choice in the context of standard setting. Extant papers assume that the standard-setting process is a one-shot game and that technologies are already developed when considering their inclusion in a standard. In this paper, instead, I allow for repeated interaction and investment in technologies as the standard is being developed.

I show that when technologies are difficult to describe ex ante, the standard may be inefficient even when firms commit to a price cap. When firms interact repeatedly to develop multiple standards, FRAND commitments may lead to more efficient technologies and higher surplus for all parties. In particular, FRAND commitments are optimal when writing ex-ante contracts is costly and the frequency of interactions of SSO members is high enough.

[1]Standards involve complementary technologies from several firms, which make it difficult to assess which specification of the standard would be optimal ex ante, even if all firms offer price caps and even if there is perfect information about the relevant patents that are held by each firm.

2. Standards, patents, and hold-up

A standard is a specification of the technical characteristics of a technology, product, or service. Standards are necessary to guarantee interoperability. For example, DVD standards specify that the width of the laser beam that reads the DVD's content must be 650 nm. Such standards are needed to guarantee that a DVD player will read a DVD disc and play its content on a video monitor –given that all these products may be manufactured by different firms.

Most standards nowadays include component technologies that are covered by patents. If these patents cannot be invented around, they become standard-essential patents (SEPs). DVD standards, for example, are covered by more than 800 US essential patents, which have been contributed by 18 firms (Joshi and Nerkar, 2011).

In recent years, there is growing concern that SEPs may induce opportunistic behavior (hold-up) on the part of patent holders[2]. This idea is well exemplified by Qualcomm's alleged behavior in the development of the Universal Mobile Telecommunications System (UMTS) standard.

The European Telecommunications Standards Institute (ETSI) chose UMTS as the standard in wireless communication, after screening different technologies. Before UMTS was chosen, Qualcomm agreed to license its related patents on "fair and reasonable" terms. However, after ETSI chose UMTS as the standard –discarding alternative technologies such as CDMA2000– Qualcomm allegedly held-up the industry by setting higher-than-expected licensing fees.

Most firms that are involved in the development of standards participate in several standard-setting processes –both at a given point in time and across

[2]See, for example, Shapiro (2001); Farrell, Hayes, Shapiro, and Sullivan (2007); Schmalensee (2009); Llanes and Poblete (2014); and Lerner and Tirole (2015).

time. For example, Updegrove (2003) shows that in 2003 Sun Microsystems and HP were participating in more than 150 SSOs each, and DeLacey, Herman, Kiron, and Lerner (2006) show that a handful of firms interacted repeatedly to develop the different generations of the 802.11 (Wi-Fi) and DSL standards.

With repeated interaction, a firm may refrain from engaging in opportunistic behavior because setting a high price would adversely affect its participation in future SSOs. I consider FRAND commitments as relational contracts that implement the outcome of a repeated game, and I argue that this is the reason why we have seen so few cases of hold-up happening in reality –even though the threat of hold-up is very significant from a theoretical point of view.[3]

The idea that repeated interaction may help agents avoid hold-up problems is well known in economics. The contribution of this paper is to bring this idea into the discussion of the optimal rules of SSOs, and to show that when technologies are difficult to describe ex ante, FRAND commitments may outperform ex-ante agreements. To the best of my knowledge, this is the first paper to offer a formal model that delivers this result in the standards literature.[4]

Traditional models of standard setting take the development of standard-related technologies as given.[5] However, in most cases technologies are developed at the same time as the standard. For example, when developing the 802.11n (Wi-Fi) standard, a technical group inside the Institute of Electrical and Electronics Engineers (IEEE) investigated ways to increase transmission rates, which required significant investments from Intel and other firms (DeLacey,

[3]In the real world, the existence of a FRAND commitment and the option of taking the patent holder to court may provide additional constraints on opportunistic behavior.

[4]Larouche and Schuett (2017) study a repeated model of standard setting, but they focus on the voting rules of SSOs, not on the comparison between different licensing rules.

[5]See, for example, Schmidt (2008); Simcoe (2012); Farrell and Simcoe (2012); Layne-Farrar, Llobet, and Padilla (2014); Llanes and Poblete (2014); and Lerner and Tirole (2015).

Herman, Kiron, and Lerner, 2006). I incorporate this more realistic assumption into the analysis.

3. The model

A Standard-setting organization (SSO) may use a firm's patented technology to develop a standard that will be used by a continuum of users of mass one. The SSO is a non-profit organization, controlled by a board that is composed of agents with stakes on the standard, such as for-profit firms, governmental agencies, and significant users. For simplicity, as I explain in detail below, I assume that there is a single firm that owns the relevant patents (see below) and that the SSO's board chooses the technical characteristics of the standard to maximize a weighted function of the firm's profit and users' surplus. The relative weight of firm profit and user surplus in the SSO's objective function represents the differential bargaining power of these agents within the SSO's board.

The SSO can base the standard on one of two alternative technologies: 0 and 1.[6] Technology 1 can potentially lead to a better standard than can technology 0. For simplicity, I assume that technology 0 is unprotected by patents, while technology 1 is protected by patents that are owned by the firm.[7]

Standardization generally requires specific investments from users, which are sunk after the standard is developed (Farrell, Hayes, Shapiro, and Sullivan, 2007).

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[6]SSOs can often choose between two or more technologies when developing a standard. For example, in the case of the 802.11g (Wi-Fi) standard, IEEE had to choose between the Orthogonal Frequency Division Multiplexing (OFDM) and Packet Binary Convolution Coding (PBCC) technologies, which were sponsored by Intersil and Texas Instruments respectively (see DeLacey, Herman, Kiron, and Lerner, 2006, for details).

[7]The paper can be extended in a straightforward manner to allow for competition between patented technologies.

These specific investments may include the acquisition or development of complementary goods, and the costs of coordinating to adopt the same standard. Specific investments create switching costs that make it difficult for adopters to change to a different standard. For simplicity, I assume that once the SSO commits to a technology, its decision cannot be reverted.[8]

The value of a standard is the total surplus that is generated by users, who may be consumers of goods based on the standard or downstream firms that produce intermediate or final goods. Users' utility when paying price p to use a standard with value v is $v - p$, and their utility if they do not adopt or use a standard is normalized to 0.

Technology 0 yields a standard that users value at $\underline{v}$. Technology 1 yields a standard with value $\overline{v}$ with probability x and value $\underline{v}$ with probability $1 - x$, where $0 < \underline{v} < \overline{v} < 1$ and x is the firm's non-contractible research effort.[9]

Given that technology 0 is not protected by patents, if this technology is selected as the standard users do not have to pay licensing fees and their expected utility is $u = \underline{v}$. If technology 1 is selected, and given an investment x by the firm, a price p' if value is $\overline{v}$, and a price p'' if value is $\underline{v}$, users' expected utility is

$$u = x\,(\overline{v} - p') + (1 - x)\,(\underline{v} - p'').$$

Note that if technology 1 is selected as the standard, the standard is covered by the firm's patents even if the value realization of technology 1 is $\underline{v}$.

[8]It is straightforward to extend the model to include a cost of reverting technology choices. The main results of the paper will hold as long as this cost is sufficiently large. If the cost is small, hold-up is not a significant problem, and technological decisions are efficient.

[9]The low outcome for technology 1 is assumed to be equal to technology 0's value for simplicity. The assumption is not essential for the paper's results: Analogous results would be obtained if the low outcome for technology 1 was greater or smaller than $\underline{v}$ (although, of course, the bounds in Propositions 1 to 3 would have to be adapted).

If technology 0 is selected as the standard, the firm obtains zero profit. If technology 1 is selected as the standard, the firm can exert research effort $x \in [0, 1]$ at cost $\frac{1}{2}x^2$. In this case, given effort x, price p' if value is $\overline{v}$, and price p'' if value is $\underline{v}$, the firm's expected profit is

$$\pi = x\,(\overline{v} - p') + (1 - x)\,(\underline{v} - p'') - \frac{1}{2}\,x^2.$$

As mentioned above, the SSO wants to maximize a function of the expected surplus that is obtained by the users of the standard and the profit of the firm,

$$U = u + \alpha\,\pi,$$

where $\alpha \in [0, 1]$ is a parameter that measures the bargaining power of the firm in the SSO or the level of sponsor-friendliness of the standard. For example, α may represent the relative importance of corporate members versus users on the SSO's board. See Lerner and Tirole (2006) for a detailed discussion of the meaning of parameter α in a similar specification.

Following Aghion and Tirole (1994), I assume that the exact nature of technology 1 is ill-defined ex ante, so that the firm and the SSO cannot contract for delivery of a specific innovation. Thus, the firm and the SSO cannot sign contracts that are contingent on the realization of the value of the standard. The purpose of developing a standard is precisely to determine the characteristics of a technology, so it is difficult to contract on these characteristics ex ante.

In the next sections, I study three games that are based on different contracting frameworks. First, I study a game in which the firm and consumers negotiate licensing fees ex post (ex-post licensing). Second, I study a game in which the firm commits to a price cap before the standard is set (ex-ante licensing). Third, I study relational contracts in a repeated game with ex post negotiation of licensing fees (FRAND commitments).

Before delving into the analysis of the three games, in the next section I study the socially efficient standard.

4. Socially-optimal standard

Expected welfare is $W = u + \pi$. If technology 0 is adopted as the standard, welfare is $\underline{v}$. If technology 1 is adopted, welfare is $x\,\overline{v} + (1-x)\,\underline{v} - \frac{1}{2}\,x^2$.

It is straightforward to see that it is socially-optimal to adopt technology 1 and to choose research effort $\hat{x} = \overline{v} - \underline{v}$.

I will find it useful to define

$$\Delta = \frac{\hat{x}\,\overline{v} + (1-\hat{x})\,\underline{v} - \underline{v}}{\underline{v}} = \frac{(\overline{v} - \underline{v})^2}{\underline{v}}.$$

as the expected increase in value from adopting technology 1 normalized by the value of technology 0, given the socially optimal research effort.

Note that if the SSO could choose a technology, price, and research effort to maximize its objective function subject to the firm's having non-negative profits, then it would choose technology 1 and the efficient research effort $\hat{x}$. Therefore, the optimal decisions from the point of view of society are also optimal from the perspective of the SSO.

5. Ex-post licensing: hold-up

In this section, I study a one-shot game in which licensing fees are determined after the standard is set. Given that the game is played only once, SSO and users know that any ex ante commitment by the firm to set "fair and reasonable" licensing fees is meaningless. In Section 7, I study under what conditions repeated interaction can limit such opportunistic behavior.

I study the following three-stage game: First, the SSO chooses a technology for the standard. Second, the firm chooses its research effort. Third, the value of technology 1 is realized, the firm chooses a licensing fee p, and users decide whether to adopt the standard. The following proposition states the equilibrium of the game (all proofs are in the Appendix).

Proposition 1 (Ex-post licensing)**.** *The SSO chooses technology 1 if and only if* $\Delta \geq 2\,\frac{1-\alpha}{\alpha}$*. As the degree of sponsor-friendliness of the standard (α) increases, it is more likely that the SSO chooses technology 1. If technology 1 is selected, the firm chooses the efficient level of research effort.*

Even though technology 1 has the potential of providing a better standard, users know that the firm will choose royalty fees to extract all surplus (the firm will choose a price equal to the value realization). Therefore, users' surplus if technology 1 is selected as the standard is zero.

The SSO's technology choice depends on the firm's bargaining power vis-a-vis users. Thus, the SSO will choose technology 1 only if the weight that is given to firm's profit in its objective function is sufficiently large. If $\alpha = 0$, then the SSO's objective function coincides with users, and technology 1 is never adopted. As α gets closer to 1, the firm's profits become more important, and technology 1 is more likely to be adopted. If $\alpha = 1$, the SSO's objective function is equal to social welfare, and technology 1 is always adopted.[10]

[10]The traditional model of hold-up obtains if $\alpha = 0$, in which case the standard is selected solely taking into account users' utility, who expect full appropriation of value by the firm. All results

Proposition 1 reflects the classic hold-up problem that is caused by the difficulty to revert technology choices in standard setting, as exemplified by Qualcomm's alleged behavior. Given an optimal research effort, the expected value of technology 1 is $\underline{v}+(\overline{v}-\underline{v})^2$. If the firm and the SSO could contract upon the research effort or the value of the standard, they could negotiate an ex ante license between 0 and $(\overline{v}-\underline{v})^2$ and achieve efficiency. However, the non-contractibility of these variables implies that ex-post licenses will be larger than $(\overline{v}-\underline{v})^2$ in expected value.

In the following sections, I study ways to limit the firm's opportunistic behavior and improve the efficiency of the standard-setting process.

6. Ex-ante licensing: price caps

Suppose now that the SSO requires the firm to set a maximum licensing fee (price cap) before choosing a technology. The timing of the game is the same as in the previous section, except that now there is a prior stage in which the firm selects its price cap. In the last stage of the game, the firm will set the actual licensing fee to be paid by the users of the technology, but this licensing fee will have to be smaller than or equal to the price cap that is set in the first stage.

Let $\overline{p}$ represent the price cap that is selected by the firm. If $\Delta \geq 2\,\frac{1-\alpha}{\alpha}$, technology 1 is adopted in the absence of a price cap (see Proposition 1). Thus, the firm can choose $\overline{p} \geq \overline{v}$ and obtain all of the surplus.[11] If $\Delta < 2\,\frac{1-\alpha}{\alpha}$, the firm has an incentive to choose $\overline{p} < \overline{v}$ to induce the SSO to select technology 1.

in the paper hold if $\alpha = 0$, but it is also interesting to study comparative statics results as α changes.

[11] Choosing a price cap that is larger than $\overline{v}$ is equivalent to refusing to set a price cap. This action could also be interpreted as the firm's leaving the SSO. However, leaving the SSO may also affect the firm's bargaining power in the SSO. Leaving the SSO has the same effect as refusing to set a price cap if the firm's bargaining power is unaffected.

On the other hand, if $\overline{p} \leq \underline{v}$, then the firm's optimal effort is 0 and the SSO's value from adopting technology 1 is $\underline{v} - (1 - \alpha)\overline{p}$. Thus, the SSO adopts technology 0 if $\alpha < 1$ and is indifferent if $\alpha = 1$.

Therefore, for the price cap to improve technology choice, it must be such that in equilibrium $\underline{v} < \overline{p} < \overline{v}$. Proposition 2 characterizes the equilibrium:

Proposition 2 (Ex-ante licensing)**.** *The SSO chooses technology 1 if and only if* $\Delta \geq 2\left(2-\alpha\left(3-\alpha\right)\right)$. *Price caps enlarge the area of parameters for which technology 1 is selected. If* $2\left(2-\alpha\left(3-\alpha\right)\right) \leq \Delta \leq 2\,\frac{1-\alpha}{\alpha}$, *the firm chooses an inefficient level of research effort.*

Proposition 2 shows that price caps can improve technological choices by limiting the firm's opportunistic behavior. If the firm commits to a price cap, the SSO and users can be certain that prices will be below this level.

However, there is still an area of parameters for which technology 1 fails to be adopted. In particular, if α and Δ are small, inducing the SSO to adopt technology 1 requires setting a price cap smaller than $\underline{v}$, but then the firm would have no incentives to exert a positive level of research effort.

The above problem could be solved if the firm could commit ex ante to charging different prices for different realizations of the value. However, the non-contractibility of the research output implies that the firm and the SSO cannot sign contracts contingent on the value of the technology.

Proposition 2 also shows that the firm may have insufficient incentives to invest in technology 1, even if technology 1 is adopted as the standard. The reason is that if the firm is forced to choose $\overline{p} < \overline{v}$ to induce the selection of technology 1, it appropriates less than the full value of the standard, and has suboptimal incentives to exert effort to improve it.

Once again, this problem could be solved if the firm could commit to choosing the efficient level of research effort ex ante, but this solution is precluded by the non-contractibility of the firm's investment. In the next section, I study whether relational contracts can improve technological decisions over price caps.

7. Repeated interaction: FRAND commitments

In this section, I study a model of repeated standard setting with ex post determination of licensing fees.

As I explain in Section 5, in a one-stage game the commitment to set "fair and reasonable" licensing fees is inherently ambiguous and difficult to enforce in a court of law. Thus, the firm has incentives to renege on any promises it makes before its technology is chosen as the standard.[12]

However, if the firm expects to interact with other SSO members to develop future versions of the standard or to develop other standards, it may have incentives to conform to its ex ante promises. In this case, an ambiguous commitment such as FRAND may improve the standard-setting process.

The timing of the game is the same as in the ex-post licensing game of Section 5. The only difference is that now the game is a repeated game.[13] Let δ represent the discount factor of the firm and the SSO. The discount factor

[12]Following complaints by Ericsson, Nokia, Texas Instruments, Broadcom, NEC, and Panasonic that Qualcomm was setting excessively large royalty fees, the European Commission opened proceedings against Qualcomm. As the investigation was being carried out, all complainants withdrew or indicated their intention to withdraw their complaints, after which the Commission ended its probe. As this example shows, in practice it is difficult to prove that hold-up is taking place and that licensing fees are unreasonable from an ex ante perspective.

[13]Clearly, the standard-setting process is dynamic but non stationary, as technologies evolve and firms interact in different standards. The assumption of stationarity is a simplifying assumption only made to focus on the implications of repeated interaction among SSO's members. Similar results can be obtained in a non-stationary dynamic model.

can be interpreted as the probability that the relationship continues in a future standard-setting effort.[14]

Allowing for repeated interaction is important because most firms participate in several standard-setting processes both at a given point in time and across time. For example, Updegrove (2003) shows that in 2003 Sun Microsystems and HP were participating in more than 150 SSOs each, and DeLacey, Herman, Kiron, and Lerner (2006) show that a handful of firms interacted repeatedly to develop the different generations of the 802.11 (Wi-Fi) and DSL standards.

Suppose that players agree on "reasonable" licensing fees $\overline{r} \leq \overline{v}$ and $\underline{r} \leq \underline{v}$ that should be set by the firm if the value realizations are $\overline{v}$ and $\underline{v}$, respectively.

I say that the firm and the SSO cooperate in period t if the SSO chooses technology 1, and the firm chooses the optimal research effort $\hat{x}$ and sets reasonable licensing fees, depending on the realization of the value of the standard.

Consider the following grim-trigger strategies for the firm and the SSO: At period t the SSO chooses technology 1, and the firm chooses reasonable licensing fees, if both players have cooperated in all periods $s < t$. Otherwise, the SSO chooses technology 0, and the firm chooses null research effort and extracts all surplus from users. Proposition 3 characterizes the existence of an equilibrium with efficient technology adoption:

Proposition 3 (Repeated interaction with FRAND commitments)**.** *An equilibrium in which the SSO chooses technology 1 and the firm chooses the efficient research effort and reasonable licensing fees exists if and only if* $\Delta \geq \frac{2(1-\alpha)(1-\delta)}{\alpha+\delta(1-\alpha)}$.

[14]This probability may be related with the breadth of the patent portfolio of the firm. Firms that focus on developing few technologies have a smaller probability of being involved in future standard-setting efforts.

Proposition 3 shows that repeated interaction may lead to efficient technological choices, even without the use of ex ante price caps. This result is obtained if Δ, δ, and α are sufficiently large.

As Δ increases, the value from selecting technology 1 and investing to increase its expected value increases, which makes it more desirable for the firm and SSO to conform to the relational contract.

As δ increases, the future becomes more valuable relative to the present, which diminishes the incentives to deviate from the relational contract.

Finally, as α increases, the value of firm's profits on the SSO's objective function increases, which implies that the SSO accepts larger licensing fees from the firm, which make it easier for the firm to conform to the relational contract.

Note that cooperative behavior can be sustained even if firm profits have zero weight in the SSO's objective function. As $\alpha \longrightarrow 0$, there exists an equilibrium with efficient technology choice if $\Delta \geq 2\,\frac{1-\delta}{\delta}$.

Proposition 3 also shows that parameters α and δ are substitutes to induce efficient technology adoption. Thus, the firm's bargaining power in the SSO becomes less important when the interaction between the firm and other SSO members when setting standards becomes more frequent.

As $\delta \longrightarrow 0$, the condition in Proposition 3 becomes $\Delta \geq 2\frac{1-\alpha}{\alpha}$, which is the same as that in Proposition 1. Thus, repeated interaction improves the outcome of ex post licenses for any discount factor $\delta > 0$.

Comparing with price caps in a one-shot game (Proposition 2), it is straightforward to see that if

$$\delta \geq \frac{(1-\alpha)^2}{3-\alpha\,(3-\alpha)},$$

repeated interaction enlarges the area of parameters for which technology 1 is selected. Price caps improve technology choice but do not achieve full efficiency. If the discount factor is large enough, a commitment to setting reasonable fees can achieve efficiency, and thus outperform price caps.

A significant benefit of relational contracts is that they allow for greater pricing flexibility. In the one-shot game, the non-contractibility of the research output implies that the firm cannot set price caps that are contingent on the realization of the value of the technology. In a repeated game, equilibrium fees can be made to depend on this realization, which improves the ability of the firm and the SSO to conform to the relational contract, which improves technology choice.

In addition to improving technology choice, repeated interaction also leads to a more efficient research effort. In a one-shot game, equilibrium effort depends on the private marginal benefit from increasing effort. When the firm commits to a price cap, it does not appropriate the full value from its investment, and thus has suboptimal incentives to invest.

In a repeated game, on the other hand, effort can be made to depend on the "discrete" choice between conforming to the relational contract or not. Thus, the efficient research effort can be implemented even if the firm does not appropriate the full value of technological improvements.

The results of this section explain why there have been few cases of hold-up in reality, even though hold-up has been a primary cause for concern for innovation economists.[15] They also show that FRAND commitments can be a useful instrument for limiting opportunistic behavior in standard setting.

Before we move to the next section, which compares the results of the three games that were studied above, it is important to remark that FRAND commitments with repeated interaction only improve social welfare over price caps if the discount factor is large enough. In particular, if

$$\delta < \frac{(1-\alpha)^2}{3-\alpha\,(3-\alpha)},$$

then price caps provide higher welfare than do FRAND commitments.

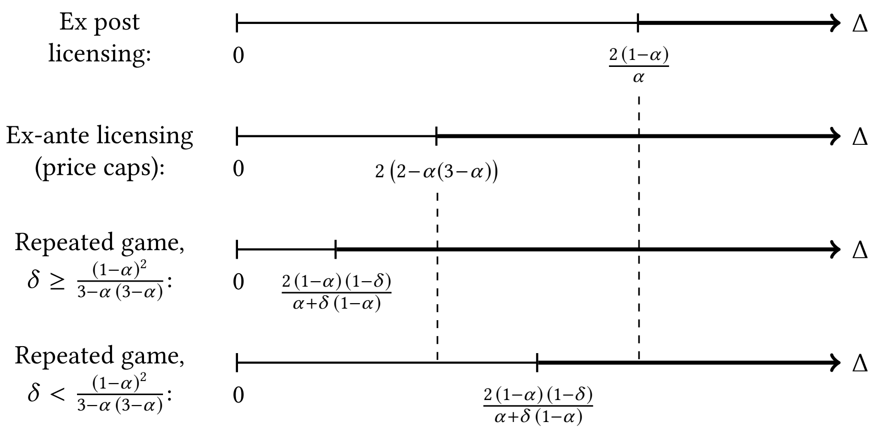
8. Comparison of results

Figure 1 illustrates the findings of Propositions 1 to 3. Thick lines represent values of Δ for which technology 1 is adopted in equilibrium.

There are several interesting implications from Figure 1. First, if Δ is large enough, then technology 1 is pursued under any licensing rule, and the potential for hold-up does not cause an inefficiency.

Second, price caps succeed in reducing the area of parameters for which the SSO chooses the inefficient technology 0 in equilibrium. However, there are still values of the parameters for which technology 0 is followed. This result happens when Δ is small, and is due to the fact that the firm cannot commit to choose prices that are contingent on the value of the technology.

[15] In a roundtable organized by the DOJ and the FTC (Farrell et al. 2002), Joseph Kattan (who was a partner in Gibson, Dunn & Crutcher) stated that hold-up "has happened, but it doesn't happen very often" (p. 21); and Paul Vishny (who was a member of D'Ancona & Pflaum, and General Counsel of the Telecommunications Industry Association) stated that hold-up is "not the kind of problem we have seen at TIA in the 600 some standards, and it's not the kind of problem that my colleagues that I've spoken to have seen in the course of their standard formulation activities" (p. 24).



Equilibrium regions: thick lines represent values of Δ for which technology 1 is chosen as the standard.

FIGURE 1. Comparison of equilibria

Third, the repeated game also reduces the area of parameters for which the SSO follows technology 0. Therefore, efficiency can be achieved without the use of explicit contracts that limit the level of ex-post licensing fees.

Fourth, if we compare the equilibria of the game with price caps and repeated interaction, we can see that if the discount factor is large enough, the area of efficient equilibria in the repeated game is larger than the corresponding area in the game with ex ante negotiations. This is because in the repeated game, the equilibrium is sustained by the behavior of the firm and the SSO *after* the standard is set and uncertainty is resolved, in contrast with ex ante negotiations, in which the equilibrium behavior depends on what the firm and the SSO know *before* the standard is determined and uncertainty is resolved.

9. FRAND vs. price caps

The relational contract between the firm and the SSO can be augmented to include price caps. It is straightforward to see that allowing for price caps in a repeated game improves upon the results of Sections 5, 6, and 7.

In particular, allowing for price caps in a repeated game diminishes the firm's temptation to deviate from the relational contract, given that if the firm wants to deviate by choosing "unreasonably" large fees (fees larger than $\overline{r}$ or $\underline{r}$), it is constrained to setting a fee that is smaller than the price cap. In comparison with the repeated game without price caps, agents have one more instrument (at no additional cost) to enforce cooperative behavior.[16]

This result means that price caps can be complementary to FRAND commitments as instruments to improve technology choice in the context of standard setting.

However, there are two reasons why it may be optimal to have FRAND commitments without price caps: First, it may be too costly to assess what the optimal royalties are before the standard is developed, because such an assessment implies a comparison of available technologies and forecasting their value, which is actually part of the standard-setting process. In contrast, FRAND commitments do not require the setting of a specific royalty rate before the standard is developed.

Second, ex ante licensing may imply larger bargaining costs and bargaining delays. Ex-ante licensing implies discussing technical and legal issues as the

[16]The SSO and the firm could introduce a price cap larger than $\overline{v}$ in their relational contract, in which case the price cap would not be effective, and the results would be analogous to those of Section 7. Thus, introducing a price cap in the repeated game can only improve the outcome of the repeated game without price caps.

standard is being developed, while with FRAND commitments legal discussions can be sidestepped until the standard is developed.[17]

Suppose that drafting a contract with price caps implies a transaction cost of $\varepsilon > 0$. Then, if FRAND commitments lead to an efficient technology choice (i.e., if $\Delta \geq \frac{2(1-\alpha)(1-\delta)}{\alpha+\delta(1-\alpha)}$), it is optimal not to include price caps in the contract between the firm and the SSO. If $\Delta < \frac{2(1-\alpha)(1-\delta)}{\alpha+\delta(1-\alpha)}$, on the other hand, including price caps in the relational contract may improve social welfare.

10. Conclusion

I study the process of standard setting and focus on the selection of technologies and the determination of licensing fees. I build a game in which an SSO has to decide which technologies should be included in a technical standard, and a firm owning patents relevant to the standard has to set the level of license fees. The structure of the game is determined by the nature of the interaction between the SSO and the firm, which is influenced by licensing rules of the SSO.

Two central assumptions of the paper are that firms interact repeatedly in different SSOs, or to develop different generations of the same standard, and that standard-related technologies are developed concurrently with the standard.

With repeated interaction, the firm may refrain from engaging in opportunistic behavior because setting a high price would adversely affect its participation in future SSOs. More important, I consider FRAND commitments as relational contracts that implement the outcome of a repeated game.

[17]Many companies send only technical specialists to standard-setting committees, and refrain from sending lawyers, given that the IP recognition and negotiation process is very slow compared to the selection of the appropriate technologies from a technical point of view. In the DOJ-FTC roundtable mentioned above, Earle Thompson, Intellectual Asset Manager and Senior Counsel at Texas Instruments, said: “Most of these standards move fairly rapidly. It takes much longer to get through the patent office” (Farrell et al. 2002).

I find that, with ex-post licensing, hold-up will always occur. Ex-ante price caps mitigate, but do not completely solve the hold-up problem. For some parameter values, the equilibrium of the repeated game implements the socially optimal standard and the efficient investment level.

FRAND commitments are optimal when writing ex-ante contracts is costly and the frequency of interactions of SSO members in different standards is large enough.[18] This result explains why standard-setting organizations favor FRAND commitments over more structured licensing commitments –such as price caps– and why there are been relatively few cases of hold-up in practice, even though hold-up has been a primary cause of concern for innovation economists.

From a public policy point of view, the paper shows that ex-ante agreements may not be needed to guarantee the development of efficient standards. If firms join technical groups with other firms with which they interact frequently in the standard-setting process, a commitment to set "fair and reasonable" licensing fees may be enough. This finding has important practical implications, because ex-ante agreements may be costly and difficult to implement in practice.

Appendix: Proofs

Proof of Proposition 1. Suppose technology 0 is used: Then, consumer surplus is $\underline{v}$, firm profit is 0, and SSO welfare is $W = \underline{v}$.

Suppose technology 1 is used: In the third stage, given realization v, firm chooses price $p = v$. In the second stage, the firm chooses x to maximize $x\overline{v} + (1-x)\underline{v} - \frac{1}{2}x^2$, which yields $x^* = (\overline{v} - \underline{v})$. Expected quality is $\underline{v} + (\overline{v} - \underline{v})^2$, firm profits are $\underline{v} + \frac{1}{2}(\overline{v} - \underline{v})^2$, consumer surplus is 0, and SSO welfare is $U = \alpha\left(\underline{v} + \frac{1}{2}(\overline{v} - \underline{v})^2\right)$.

[18]This result obtains for any positive cost of writing ex-ante contracts, no matter how small.

The SSO chooses technology 1 if and only if

$$\alpha\left(\underline{v}+\frac{1}{2}(\overline{v}-\underline{v})^2\right)\geq\underline{v}\quad\Leftrightarrow\quad\frac{(\overline{v}-\underline{v})^2}{\underline{v}}\geq 2\,\frac{1-\alpha}{\alpha}.$$

■

Proof of Proposition 2. Suppose $\Delta < 2\,\frac{1-\alpha}{\alpha}$ so technology 0 is chosen in the absence of price caps. We want to find an equilibrium with $\underline{v}\leq\overline{p}\leq\overline{v}$.

Suppose the SSO chooses technology 1: In the fourth stage, if the realization is $\underline{v}$, the firm charges $p=\underline{v}$; and if the realization is $\overline{v}$, the firm charges $p=\overline{p}$. In the third stage, the firm chooses x to maximize $x\overline{p}+(1-x)\underline{v}-\frac{1}{2}\,x^2$, which yields $x^*=\overline{p}-\underline{v}$. Expected quality is $\underline{v}+(\overline{p}-\underline{v})\,(\overline{v}-\underline{v})$, firm profits are $\underline{v}+\frac{1}{2}\,(\overline{p}-\underline{v})^2$, consumer surplus is $(\overline{p}-\underline{v})\,(\overline{v}-\overline{p})$, and SSO welfare is $U=(\overline{p}-\underline{v})\,(\overline{v}-\overline{p})+\alpha\,(\underline{v}+\frac{1}{2}\,(\overline{p}-\underline{v})^2)$.

In the second stage, the SSO will choose technology 1 if

$$(\overline{p}-\underline{v})\,(\overline{v}-\overline{p})+\alpha\,\left(\underline{v}+\frac{1}{2}\,(\overline{p}-\underline{v})^2\right)\geq\underline{v}.$$

In the first stage, the firm will choose the largest price cap possible so that the SSO chooses technology 1, which is

$$\overline{p}^*=\frac{\overline{v}+(1-\alpha)\,\underline{v}+\sqrt{(\overline{v}-\underline{v})^2-2\underline{v}\,(2-\alpha(3-\alpha))}}{2-\alpha}.$$

If $(\overline{v}-\underline{v})^2-2\,\underline{v}\,(2-\alpha(3-\alpha))<0$, then there is no price cap such that the SSO chooses technology 1. Therefore, for technology 1 to be adopted, we need

$$(\overline{v}-\underline{v})^2-2\,\underline{v}\,(2-\alpha\,(3-\alpha))\geq 0\quad\Leftrightarrow\quad\frac{(\overline{v}-\underline{v})^2}{\underline{v}}\geq 2\,(2-\alpha(3-\alpha))\,.$$

■

Proof of Proposition 3. The firm can deviate in the second or third stages. In the third stage, if the realization is $\overline{v}$, the firm does not deviate as long as

$$\overline{r} + \frac{\delta}{1-\delta} \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \geq \overline{v}. \tag{1}$$

If the realization is $\underline{v}$, the firm does not deviate as long as

$$\underline{r} + \frac{\delta}{1-\delta} \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \geq \underline{v}. \tag{2}$$

Multiplying the left- and right-hand sides of (1) by $\hat{x}$ and the left and right hand sides of (2) by $1-\hat{x}$, and adding the resulting inequalities, I obtain

$$\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} + \frac{\delta}{1-\delta} \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \geq \hat{x}\, \overline{v} + (1-\hat{x})\, \underline{v}, \tag{3}$$

$$\hat{r} \geq (1-\delta)\, \left(\hat{x}\, \overline{v} + (1-\hat{x})\, \underline{v} \right) + \delta\, \frac{1}{2}\, \hat{x}^2,$$

$$\hat{r} \geq (1-\delta)\, \hat{v} + \delta\, \frac{1}{2}\, (\overline{v} - \underline{v})^2,$$

$$\hat{r} \geq (1-\delta)\, \underline{v} + \left(1 - \frac{\delta}{2} \right)\, (\overline{v} - \underline{v})^2. \tag{4}$$

In the second stage, the firm does not deviate as long as

$$\frac{1}{1-\delta} \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \geq \max_x \left(x\, \overline{v} + (1-x)\, \underline{v} - \frac{1}{2}\, x^2 \right)$$

$$\frac{1}{1-\delta} \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \geq \hat{x}\, \overline{v} + (1-\hat{x})\, \underline{v} - \frac{1}{2}\, \hat{x}^2,$$

which is equivalent to (3).

The SSO does not deviate as long as

$$\frac{1}{1-\delta} \left(\hat{x}\, (\overline{v} - \overline{r}) + (1-\hat{x})\, (\underline{v} - \underline{r}) + \alpha \left(\hat{x}\, \overline{r} + (1-\hat{x})\, \underline{r} - \frac{1}{2}\, \hat{x}^2 \right) \right) \geq \frac{1}{1-\delta}\, \underline{v}$$

$$\hat{r} \leq (\overline{v} - \underline{v})^2 \frac{1 - \frac{\alpha}{2}}{1 - \alpha} \tag{5}$$

There exists $\hat{r}$ that is consistent with (4) and (5) as long as

$$(1 - \delta)\, \underline{v} + \left(1 - \frac{\delta}{2}\right) (\overline{v} - \underline{v})^2 \leq (\overline{v} - \underline{v})^2 \frac{1 - \frac{\alpha}{2}}{1 - \alpha},$$

$$\frac{(\overline{v} - \underline{v})^2}{\underline{v}} \geq \frac{2\,(1 - \alpha)\,(1 - \delta)}{\alpha + \delta\,(1 - \alpha)}.$$

■

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