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

GASTÓN LLANES†

ABSTRACT. I study technology choice in standard-setting organizations. I study the effects of requiring the holders of standard-related patents to commit to a maximum royalty or price cap for the use of their patents. I find that there may be inefficient adoption of technologies even when firms commit to a price cap. When firms participate in the development of multiple 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 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.

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

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†Pontificia Universidad Católica de Chile, gaston@llanes.com.ar.

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1. Introduction

Technical standards play an essential role in the development and adoption of new technologies. In recent years, there has been growing concern that the standard-setting process may be subject to opportunistic behavior (hold up) on the part of the owners of intellectual property covering technologies included in the standard (Shapiro, 2001; Farrell, Hayes, Shapiro, and Sullivan, 2007; Schmalensee, 2009).

The idea of hold up is well exemplified by the Qualcomm case in the development of the Universal Mobile Telecommunications System (UMTS) standard. The European Telecommunications Standards Institute (ETSI) chose the 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 in wireless telecommunication –discarding alternative technologies like 3G CDMA– Qualcomm allegedly held-up the industry by setting higher-than-expected licensing fees.

Hold up is rooted in the difference between ex-post and ex-ante market power. A direct consequence of hold up is a redistribution of surplus from consumers and downstream producers to the patent holder. However, opportunistic behavior may also have adverse effects on economic efficiency. First, hold up may increase the deadweight loss stemming from market power. Second, it may lead to the selection of inferior technologies, if the costs associated with hold up when choosing the best technology are high and alternative technologies are less likely to be subject to hold up.

This problem may be exacerbated when it is difficult to determine if the relevant technologies are patented or not. Patent-holders may try to hide the fact that they have patents covering these technologies until after the standard is defined. Such behavior is called *patent ambush*, and is exemplified by Rambus's alleged behavior in the development of the SDRAM memory standard.[1]

In an effort to avoid hold up, many standard-setting organizations (SSOs) require participants to disclose standard-related patents and to promise to license them on friendly, reasonable and non-discriminatory (FRAND) terms. These rules discourage hold up, but may be insufficient for at least two reasons: (i) not all companies owning patents relevant to the standard participate in the SSO, and, therefore, are not required to disclose their IP or to license them on FRAND terms; and (ii) patent-holders, SSOs and users may disagree on what is the level of licensing fees that is "fair and reasonable," as these requirements are inherently ambiguous.[2]

Some scholars and practitioners have proposed ex-ante negotiations of licensing terms, in the form of price caps, as a way to overcome the problems associated with FRAND commitments Llanes and Poblete (2014); Lerner and Tirole (2015). Others claim that price caps may fail to work because in the early stages of the standard setting process there is too much uncertainty about the existence of patents covering the technology. Even if patents are known, it may be very difficult to know what is the breadth of these patents, whether they are essential for the standard or not, and what is the value of alternative technologies. Some

[1]Rambus Inc., FTC Docket No. 9302, Opinion of the Commission 3 (Aug. 2, 2006), available at http://www.ftc.gov/os/adjpro/d9302/060802commissionopinion.pdf

[2]Swanson and Baumol (2005) and Farrell et al. (2007) argue that the "fair and reasonable" requirements are related to the ex-ante state of competition, and propose rules that courts may follow to determine if licensing fees satisfy these requirements. I am concerned with determining equilibrium behavior without litigation.

of this uncertainty could be overcome by searching for relevant IP and assessing its contribution to the standard. However, the cost of conducting a full patent search may be prohibitively high, which is why few SSOs require their members to conduct a full patent search.

Practitioners also point out that ex-ante licensing agreements may slow down the standard setting process. Many companies only send technical specialists to the 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. For example, in a round table organized by the FTC and the DOJ in 2002, 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).

In this paper, I study the process of standard formation, focusing on the selection of technologies and the determination of licensing fees. I build a game in which an SSO decides which technologies are included in a technical standard, and a firm owning patents relevant to the standard sets 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 the licensing rules set in place by the SSO.

Extant papers studying the advantages and disadvantages of different licensing rules generally assume certainty about the intellectual property covering the relevant technologies, and also assume that the technology setting process is a one-shot game, i.e. there is no repeated interaction between the participants of the standard setting process (see Llanes and Poblete, 2014; Lerner and Tirole, 2015, for example). In contrast, in this paper, I allow for probabilistic patents and repeated interaction.

Allowing for repeated interaction is important because most firms participate in several standard setting processes. For example, in 2003, Sun Microsystems and Hewlett-Packard were participating in more than 150 SSOs each (Updegrove, 2003). 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 importantly, I see FRAND commitments as relational contracts which implement the outcome of a repeated game. 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.

I study three scenarios: (i) the firm sets the licensing fee after the standard is selected (ex-post licensing), (ii) the SSO requires the firm to set a price cap before the standard is selected (ex-ante licensing), and (iii) the licensing fee is determined as the outcome of a repeated game between the firm and the SSO (relational contracts).

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, an inefficiency may arise because the SSO may chose an inferior technology in order to avoid hold up on the superior technology. I also find parameter values for which the equilibrium of the repeated game implements the socially optimal standard. Surprisingly, I find parameter values for which the equilibrium of the repeated game is more efficient than ex-ante licensing. This result is due to the fact that the firm cannot set prices contingent on the set of technologies covered by patents.

The idea that repeated interaction may help agents avoid hold up problems is well known in economics. The main contribution of the paper is to bring this idea into the discussion of the optimal rules of standard-setting organizations, and to show that when formal contracts are incomplete, 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.

2. The model

The model deals with the formation of a standard. There is a unit mass of users of the standard, and each user values the standard in $v > 0$.[3] There are two possible directions of research, $d \in \{0, 1\}$, which could lead to a successful development of the standard. Let π_d represent the probability that the standard is developed by following direction d, where $\pi_1 \geq \pi_0$. In other words, direction 1 is more promising for developing the standard. The assumption that $\pi_1 \geq \pi_0$ may also signify that direction 1 is expected to lead to a standard faster than direction 0, and that the value of the standard is discounted by the expected time difference. This feature of the model is important because many standards fail to be adopted or suffer important delays in their development process.[4]

[3]The value of the standard is the total surplus generated by the adopters of the standard, who may be final consumers of the goods based on the standard, or downstream firms producing intermediate or final goods.

[4]More generally, it could also be assumed that the value of the standard may be high or low, and that direction of research 0 implies a higher probability of getting a standard of low value. This alternative assumption would not affect the main conclusions of the paper.

The players of the game are a Standard Setting Organization (SSO) and a firm holding patents potentially relevant to the implementation of the standard. The SSO chooses the direction of research for developing the standard. Both directions may lead to a standard covered by patents owned by the firm, but the probability is higher under direction 1. Let ρ_d indicate the probability that the standard is covered by patents, where $\rho_1 \geq \rho_0$.

The assumption of probabilistic patents is used to reflect the fact that it is in general very difficult for the SSO to determine whether there are patents covering the technologies under study. As Farrell et al. (2007) state "even if a patent has been issued and disclosed to the SSO, its validity and effective scope may be unknown when the standard is selected and implemented." In addition, it may even be very difficult or too costly for the firm to search for all patents related with a standard. According to Layne-Farrar, Padilla, and Schmalensee (2007), "even companies participating in the standard setting process may not be clear on whether their patents are essential for a standard." Chiao, Lerner, and Tirole (2007) present evidence from interviews and show that the size and complexity of the firm's patent portfolios make it difficult for firms to know which of their patents read on a standard.[5]

The assumptions capture the fact that the SSO may try to reduce the standard's exposure to the firm's patents by selecting an alternative direction of research. However, choosing the alternative route also implies a lower probability of success (or a slower pace of development). The SSO cannot guarantee

[5]The standard may also infringe "submarine patents," i.e., patents which a firm *hides* from the SSO in order to extract a higher fraction of the total surplus after the standard is set. for the time being, assume that the firm has the same information than the SSO regarding the likelihood of having a patent covering the technology. Later, I will discuss what happens when the firm has better information than the SSO in this regard (asymmetric information).

that the standard will not infringe any of the firm's patents, even by choosing the alternative direction of research, as long as $\rho_0 > 0$.

The direction of research is non-contractible. Technologies evolve as standards are developed, which makes it difficult to describe ex-ante what are the implications of following one direction of research or the other. Moreover, even if contracts could include a full description of the direction of research, the research path would probably be significantly altered during the standard setting and technology development process, which would mean that the patent holders and other SSO's members would try to change the terms of the contract after the uncertainty is resolved.

After the standard is defined, if the technology selected by the SSO is found to infringe on the firm's patents, the firm will be able to demand a fraction of the surplus generated by the standard, in the form of licensing fees.

Let p be the licensing fee charged by the firm in case it has patents covering the standard. Then, the surplus obtained by users is $v - p$ and the surplus obtained by the firm is p.

The SSO wants to maximize a function of the expected surplus obtained by the users of the standard and the firm,

$$U = (v - p) + \alpha p,$$

where $\alpha \geq 0$ is a parameter measuring the bargaining power of the firm in the SSO, or the level of sponsor friendliness of the standard (Lerner and Tirole, 2006). The above expression can be rewritten as

$$U = v - \beta p,$$

where $\beta = 1 - \alpha \leq 1$, and a higher β represents a lower bargaining power for the firm *vis a vis* users in the SSO's technical committees or governing bodies. The objectives of the SSO and the firm are aligned whenever $\beta \leq 0$, in which case the SSO will always choose direction 1. Therefore, for the rest of the paper, I focus on the case $\beta > 0$.

The above assumptions are meant to reflect the fact that SSOs are usually composed by players with heterogeneous objectives. For example, the SSO's board may include firms holding patents on necessary technologies (upstream firms), producers of goods based on the standard (downstream firms), firms which hold patents and are also producers in the downstream market (integrated firms), and significant users or consumer organizations. While all members could benefit from a high quality standard, some members want low licensing fees, while other members want high licensing fees. The specification of the objective function of the SSO is designed to reflect the differential bargaining power that these members may have in the negotiation process.

Finally, the structure of the game will depend on the specific licensing rules imposed by the SSO. In particular, I consider three cases: (1) the SSO does not allow licensing negotiations ex-ante and the firm sets a licensing fee after the standard is set, (2) the SSO requires the firm to set a price cap on future licensing fees before the standard is set, and (3) the SSO and the firm enter an implicit agreement limiting ex-post licensing fees, which are formally determined as the outcome of a repeated game with uncertain end. In (1) there are no contracts between the firm and the SSO. In (2) the firm commits to honor the terms of an explicit contract. In (3) the relation between the firm and the SSO is ruled by a relational contract.

3. Solution of the model

3.1. **Ex-post licensing: hold up.** In this case, the timing of the game is the following:

(1) The SSO chooses the direction of research, $d \in \{0, 1\}$.
(2) Given d, Nature determines if the standard is successfully developed, and whether it is covered by the patents of the firm.
(3) If the standard is developed and covered by patents, the firm sets licensing fee p.

The following proposition states the equilibrium of the game.

Proposition 1. *If* $\pi_1/\pi_0 \geq (1 - \beta\,\rho_0)/(1 - \beta\,\rho_1)$*, the SSO will follow direction 1. If* $\pi_1/\pi_0 < (1 - \beta\,\rho_0)/(1 - \beta\,\rho_1)$*, the SSO will follow direction 0. In both cases,* $p = v$ *if the standard is covered by patents.*

Several important implications arise from the previous proposition. First, the firm will always engage in hold up when it has patents covering the standard. However, in expected terms, the firm will obtain a payment of $\pi_d\,\rho_d\,v$, which is less than the total surplus generated by the standard.

Second, the equilibrium direction of research depends on the comparison between the difference in the probability of success, and the difference in the probabilities of hold up.

If the difference is success probabilities is not very high in comparison with the difference in probabilities of hold up, the SSO will choose a suboptimal direction of research. Hold up implies that the SSO will obtain an expected payoff of $\pi_1\,v\,(1 - \beta\,\rho_1)$ if it selects direction 1, which is less than the expected payoff it would obtain by selecting direction 0. Therefore, the possibility of opportunistic behavior generates the inefficient adoption of a suboptimal direction of research.

3.2. **Ex-ante licensing: price caps.** Suppose now that the SSO requires the firm to set a maximum licensing fee (price cap) before choosing the direction of research. The timing of the game is the same as in the previous case, except that now there is an additional first 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 set in the first stage.

Let $\bar{p}$ represent the price cap selected by the firm. Proposition 2 presents the equilibrium of the game.

Proposition 2. *Let* $\theta_1 = (1 + \beta\,\rho_0)\,/\,2 + \sqrt{(1 + \beta\,\rho_0)^2\,/\,4 - \beta\,\rho_0\,/\,\rho_1}$ *and* $\theta_2 = (1 - \beta\,\rho_0)\,/\,(1 - \beta\,\rho_1)$*, where* $1 < \theta_1 < \theta_2 < \infty$*. The equilibrium exists and is unique. There are three equilibrium regions:*

(i) *If* $\pi_1/\pi_0 < \theta_1$ *then* $\bar{p} \geq v$, $p = v$ *and the SSO follows* $d = 0$.

(ii) *If* $\theta_1 \leq \pi_1/\pi_0 < \theta_2$ *then* $p = \bar{p} = \frac{\pi_1 - \pi_0}{\beta\,(\pi_1\,\rho_1 - \pi_0\,\rho_0)}\,v$*, where* $\bar{p} < v$ *and the SSO follows direction 1.*

(iii) *If* $\pi_1/\pi_0 \geq \theta_2$ *then* $\bar{p} \geq v$, $p = v$*, and the SSO follows* $d = 1$.

Proposition 2 has several interesting implications. First, the possibility of ex-ante negotiations reduces the area of parameters for which the equilibrium is inefficient. However, there is still an area of parameters for which the equilibrium is suboptimal (area i). The reason for this inefficiency is that contracts are incomplete: the firm cannot set a price cap contingent on the direction of research chosen, only on the realization of v. As a consequence, when the firm sets a lower price cap, it increases the desirability of following not only direction 1, but also direction 0, which means that the price cap needed to motivate direction 1 is larger than what it would be in the case of complete contracts.

Second, when $\theta_1 \leq \pi_1/\pi_0 < \theta_2$ (area ii), the firm sets a price discount ex-ante, so that direction 1 is followed. In this case, the greater probability of success and of having patents covering the standard implied by direction 1 compensate the firm for the lower licensing fees. When $\pi_1/\pi_0 < \theta_1$ (area i), on the other hand, the discount the firm would have to offer to motivate adoption of direction 1 would be too high in relative terms, and then the firm finds it optimal to settle for a higher price cap and direction 0.

3.3. **Repeated interaction.** The timing of the game is the same as in the ex-post licensing game (Section 3.1). The only difference is that now the game is a repeated game with uncertain end. Let δ represent the discount factor of the firm and the SSO. The discount factor can be interpreted as the probability that the relationship between the firm and the SSO continues in a future standard setting effort. In my model, this probability will be related with the breadth of the patent portfolio of the firm. Firms which focus on developing few technologies have a smaller probability of being involved in future standard setting efforts, and consequently have a smaller discount factor.

Let $d_t \in \{0, 1\}$ be the direction or research followed by the SSO in period t and consider the following trigger strategies for the firm and the SSO (remember that the firm chooses p_t after observing d_t):

$$d_t = \begin{cases} 1 & \text{if } p_k \le R \text{ for } k \le t-1, \\ 0 & \text{otherwise,} \end{cases}$$

$$p_t = \begin{cases} R & \text{if } d_k = 1 \text{ for } k \le t, \\ v & \text{otherwise.} \end{cases}$$

where R is the maximum fee that the SSO will tolerate without punishing the firm by choosing direction 0 in all subsequent periods. Proposition 3 shows the equilibrium of the repeated game.

Proposition 3. *Let $\theta_R = (1-\beta\,\rho_0)\,(1-\beta\,\rho_1 + \frac{\delta}{1-\delta}\,\rho_1\,(\pi_1-\pi_0))^{-1}$. If $\pi_1/\pi_0 \ge \theta_R$, there is a continuum of equilibria in which $d_t = 1$ and $p_t = R$ for all t, such that*

$$\frac{1-\delta(1-\pi_0\,\rho_0)}{1-\delta(1-\pi_1\,\rho_1)}\,v \le R \le \frac{\pi_1 - \pi_0(1-\beta\,\rho_0)}{\beta\,\pi_1\,\rho_1}\,v.$$

If $\pi_1/\pi_0 < \theta_R$, on the other hand, any R is an equilibrium and $d_t = 0$ and $p_t = v_0$ for all t.

Proposition 3 shows that repeated interaction may lead to adoption of direction 1, even without requiring the use of ex-ante price caps.

In Section 3.2 I showed that with price caps, there was a region of parameters for which the equilibrium was inefficient. The following proposition shows under which conditions repeated interaction will reduce the area of parameters for which suboptimal technologies are chosen, in comparison with ex-ante negotiations.

Proposition 4. *The area of values of π_1 for which direction 1 is followed in equilibrium is larger with repeated interaction, in comparison with price caps, if and* *only if*

$$\frac{\delta}{1-\delta} > \frac{1}{2\,\beta\,\pi_0\,\rho_0{}^2}\left(\beta\,\rho_0 - 1 + \sqrt{(1+\beta\rho_0)^2 - \frac{4\,\beta\,\rho_0{}^2}{\rho_1}}\right).$$

The condition in Proposition 4 can be rewritten as follows:

$$\delta \;>\; \hat{\delta} = \frac{\beta\,\rho_0 - 1 + \sqrt{(1+\beta\rho_0)^2 - \frac{4\,\beta\,\rho_0{}^2}{\rho_1}}}{2\,\beta\,\pi_0\,\rho_0{}^2 + \beta\,\rho_0 - 1 + \sqrt{(1+\beta\rho_0)^2 - \frac{4\,\beta\,\rho_0{}^2}{\rho_1}}}$$

Proposition 4 shows that repeated interaction may lead to better outcomes than price caps. Not surprisingly, the condition depends on the discount factor. For any value of π_0, ρ_0, π_1, ρ_1, and β, if the discount factor is large enough, repeated interaction will lead to a larger region of efficient equilibria.

Of course, the discount factor may very well be below the threshold implied by Proposition 4, in which case repeated interaction implies a smaller region in which direction 1 is followed. Therefore, it is interesting to determine the effects of changes in the other parameters in the comparison of equilibria of the two games. Proposition 4 implies that the region of parameters for which repeated interaction leads to direction 1, and ex-ante negotiations leads to direction 0, becomes larger as (i) the probability of having patents with the inefficient (efficient) direction of research increases (decreases), (ii) the bargaining power of the firm in the SSO decreases, and (iii) the probability of success of the inefficient direction of research increases.

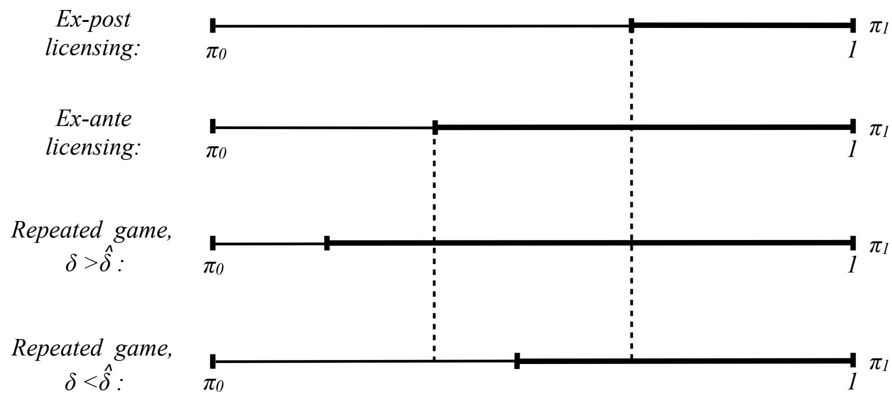
Finally, it is straightforward to show that the licensing fee with price caps is always smaller than the upper bound of the "reasonable" fee with repeated interaction (R), but may be larger or smaller than the lower bound. For π_1 and δ large enough, and for π_0 and β low enough, the lower bound for R will be smaller than the price cap. Therefore, prices may be higher or lower with price caps, in comparison with prices under repeated interaction.

A surprising finding is that repeated interaction may lead to higher prices than ex-ante negotiations, but to a larger region of efficient equilibria. This is a consequence of the incompleteness of contracts and the difference in the timing of pricing decisions. With price caps, lowering the price ex-ante affects the incentives to follow *both* directions of research, because the price cap cannot be made contingent on the direction of research followed. As a consequence, to motivate adoption of direction 1, the firm will have to commit to a lower price cap than the one it could set if contracts were complete. With repeated interaction, on the other hand, the price is determined once a direction of research has been followed and all uncertainty has been realized, and the firm can make its strategy be contingent on the direction of research followed by the SSO. Therefore, prices *may* be larger than prices with ex-ante negotiations, but still lead to adoption of the socially optimal direction of research.

3.4. **Comparison of results.** Figure 1 summarizes the findings of Propositions 1 to 3 and Proposition 4. Bold lines represent values of π_1 for which technology 1 is adopted in equilibrium.

There are several interesting implications from Figure 1. First, if π_1 is much larger than π_0, then direction 1 is followed 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 follows direction 0 in equilibrium. However, there are still values of the parameters for which direction 0 is followed. This result happens when π_1 is



Equilibrium regions: bold lines represent values of π_1 for which $d = 1$ in equilibrium.

FIGURE 1. Comparison of equilibria

not much larger than π_0, and is due to the fact that the firm cannot commit to separate prices for $d = 0$ and $d = 1$.

Third, the repeated game also reduces the area of parameters for which the SSO follows direction 0. Therefore, efficiency can be achieved without the use of explicit contracts limiting 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 direction of research is chosen 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 direction of research is selected and uncertainty is resolved.

4. Conclusion

I study the process of standard formation, focusing 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 the licensing rules of the SSO.

A central assumption of the paper is that of probabilistic patents. I also analyze the equilibrium of the game under repeated interaction, which is important because most firms participate in several standard setting processes. For example, Sun Microsystems and Hewlett-Packard participate in more than 150 SSOs. 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 importantly I see FRAND commitments as relational contracts which implement the outcome of a repeated game. I argue that this is the reason why we have seen so few cases of hold up happening in reality, even though hold up is a very important threat in theory.

I study three scenarios: (i) the firm sets the licensing fee after the standard is selected (ex-post licensing), (ii) the SSO requires the firm to set a price cap before the standard is selected (ex-ante licensing), and (iii) the licensing fee is determined as the outcome of a repeated game between the firm and the SSO (relational contracts).

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, an inefficiency may arise because the SSO may chose an inferior technology in order to avoid hold up on the superior technology. I also find parameter values for which the equilibrium of the repeated game implements the socially optimal standard. Surprisingly, I find parameter values for which the equilibrium of the repeated game is more efficient than ex-ante licensing. This result is due to the fact that the firm cannot set prices contingent on the set of technologies covered by patents.

These findings are important because they allow us to understand why there have been so few cases of hold up in reality, despite the significant threat that opportunistic behavior poses from a theoretical point of view. Moreover, they also allow us to understand the rationale behind FRAND commitments, which may help reach an implicit contract between the different members of Standard Setting Organizations.

Appendix: Proofs

Proof of Proposition 1. If the standard is covered by patents, the firm can always demand a payment equal to v. Therefore, the expected payoff of the SSO under direction d is $\pi_d \, v \, (1 - \beta \, \rho_d)$. Comparing the expected payoffs under both directions I obtain the stated result. ■

Proof of Proposition 2. From Proposition 1 I know that if $\pi_1 \, (1 - \beta \, \rho_1) \geq \pi_0 \, (1 - \beta \, \rho_0)$ the SSO will choose direction 1 even if the firm does not set a price cap. In what follows, suppose $\pi_1 \, (1 - \beta \, \rho_1) < \pi_0 \, (1 - \beta \, \rho_0)$.

If the firm commits to a price cap $\bar{p}$, the SSO will choose $d = 1$ if and only if

$$\pi_1 \left((1 - \rho_1)\, v + \rho_1 \,(v - \beta \bar{p})\right) \;\geq\; \pi_0 \left((1 - \rho_0)\, v + \rho_0 \,(v - \beta \bar{p})\right).$$

The firm will set the largest possible price cap, which is $\bar{p} = \frac{\pi_1 - \pi_0}{\beta(\pi_1 \rho_1 - \pi_0 \rho_0)}\, v$. Alternatively, the firm could set $\bar{p} \geq v$, which would imply that $d = 0$. The firm will prefer $d = 1$ if and only if

$$\pi_1\, \rho_1\, \frac{\pi_1 - \pi_0}{\beta(\pi_1 \rho_1 - \pi_0 \rho_0)}\, v \;\geq\; \pi_0\, \rho_0\, v$$

Rearranging the above inequality I obtain

$$\left(\frac{\pi_1}{\pi_0} - 1\right) \frac{\pi_1}{\pi_0} - \beta\, \pi_0 \left(\frac{\pi_1}{\pi_0} - \frac{\rho_1}{\rho_0}\right) \;\geq\; 0 \tag{1}$$

The left hand side of (1) has two roots and a minimum (as a function of π_1/π_0). One of the roots is smaller than 1 and the other one larger than 1. To see this, notice that if we let $\pi_1/\pi_0 = 1$ in the left hand side of (1), we obtain a negative expression. The largest root is

$$\theta_1 = \frac{1 + \beta\, \rho_0}{2} + \sqrt{\left(\frac{1 + \beta\, \rho_0}{2}\right)^2 - \frac{\beta\, \rho_0}{\rho_1}}.$$

Finally, letting $\pi_1/\pi_0 = \theta_2 = \frac{1 - \beta\, \rho_0}{1 - \beta\, \rho_1}$ in the left hand side of (1) we obtain a positive expression, which means that that $\theta_1 < \theta_2$. Collecting all partial results we obtain that the firm will prefer a price cap with $d = 1$ if and only if $\pi_1/\pi_0 \geq \theta_1$. If $\pi_1/\pi_0 < \theta_1$, on the other hand, the firm will set any $\bar{p} \geq v$, which will lead to $d = 0$. ∎

Proof of Proposition 3. If the SSO chooses $d = 1$ every period, it obtains profits equal to

$$\sum_{t=0}^{\infty} \delta^t \, \pi_1 \, (v - \beta \, \rho_1 \, R) = \frac{\pi_1 \, (v - \beta \, \rho_1 \, R)}{1 - \delta}.$$

If the SSO deviates by choosing $d = 0$, it obtains profits equal to

$$\sum_{t=0}^{\infty} \delta^t \, \pi_0 \, (v - \beta \, \rho_0 \, v) = \frac{\pi_0 \, (v - \beta \, \rho_0 \, v)}{1 - \delta}.$$

Comparing profits, we obtain the condition for the SSO not to deviate:

$$R \;\le\; \frac{1}{\beta\rho_1}\left(1 - \frac{\pi_0}{\pi_1}(1 - \beta\rho_0)\right) v.$$

If the firm chooses $p \le R$ every period, it obtains profits equal to

$$R + \sum_{t=1}^{\infty} \delta^t \, \pi_1 \, \rho_1 \, R = \left(1 + \frac{\delta}{1 - \delta} \, \pi_1 \, \rho_1\right) R.$$

If the firm deviates by choosing $p = v$, it obtains profits equal to

$$v + \sum_{t=1}^{\infty} \delta^t \, \pi_0 \, \rho_0 \, v = \left(1 + \frac{\delta}{1 - \delta} \, \pi_0 \, \rho_0\right) v.$$

Comparing profits, we obtain the condition for the firm not to deviate:

$$R \;\ge\; \frac{1 - \delta \, (1 - \pi_0\rho_0)}{1 - \delta \, (1 - \pi_1\rho_1)} \, v.$$

An equilibrium with $p = R$ and $d = 1$ will exist only if the upper bound on R is larger than the lower bound. Working with the resulting inequality we obtain the condition stated in the proposition. ■

Proof of Proposition 4. For direction 1 to be followed with price caps:

$$\pi_1 \;\ge\; g(\pi_0) = \frac{\pi_0}{2}\left(1 + \beta\rho_0 + \sqrt{(1 + \beta\rho_0)^2 - \frac{4\beta{\rho_0}^2}{\rho_1}}\right)$$

For direction 1 to be followed with FRAND:

$$\frac{\delta}{1-\delta} \geq \frac{\pi_0(1-\beta\rho_0) - \pi_1(1-\beta\rho_1)}{\pi_1\rho_1\,(\pi_1-\pi_0)}.$$

Suppose the first condition is not met, but the second one is. Then,

$$\begin{aligned}
\frac{\delta}{1-\delta} &\geq \frac{\pi_0\,(1-\beta\rho_0) - \pi_1\,(1-\beta\rho_1)}{\pi_1\,\rho_1\,(\pi_1-\pi_0)} \\
&> \frac{\pi_0\,(1-\beta\rho_0) - g(\pi_0)\,(1-\beta\rho_1)}{g(\pi_0)\,\rho_1\,(g(\pi_0)-\pi_0)} \\
&> \frac{1}{2\,\beta\,\pi_0\,{\rho_0}^2}\left(\beta\,\rho_0 - 1 + \sqrt{(1+\beta\rho_0)^2 - \frac{4\,\beta\,{\rho_0}^2}{\rho_1}}\right).
\end{aligned}$$

Likewise, if the first condition is met, but not the second one,

$$\begin{aligned}
\frac{\delta}{1-\delta} &< \frac{\pi_0\,(1-\beta\rho_0) - \pi_1\,(1-\beta\rho_1)}{\pi_1\,\rho_1\,(\pi_1-\pi_0)} \\
&< \frac{\pi_0\,(1-\beta\rho_0) - g(\pi_0)\,(1-\beta\rho_1)}{g(\pi_0)\,\rho_1\,(g(\pi_0)-\pi_0)} \\
&< \frac{1}{2\,\beta\,\pi_0\,{\rho_0}^2}\left(\beta\,\rho_0 - 1 + \sqrt{(1+\beta\rho_0)^2 - \frac{4\,\beta\,{\rho_0}^2}{\rho_1}}\right).
\end{aligned}$$

Therefore, given π_0, ρ_0, ρ_1 and β, the area of values of π_1 for which $d = 1$ in equilibrium is larger for FRAND, in comparison with price caps, if and only if the condition shown in the proposition holds. ■

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