Payments and Participation: The Incentives to Join Cooperative Standard Setting Efforts*

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Abstract

This paper studies the effects of a Standard Setting Organization (SSO) imposing a licensing cap for patents incorporated into a standard. In particular, we evaluate the "Incremental Value" rule as a way to reward firms that contribute technology to a standard. This rule has been proposed as a means of avoiding patent hold-up of licensing firms by granting patent holders compensation equal to the value that their technology contributes to the standard on an ex-ante basis, as compared to the next best alternative. Our analysis shows that even in contexts where this rule is efficient from an ex-post point of view, it induces important distortions in the decisions of firms to innovate and participate in the SSO. Specifically, firms being rewarded according to this rule will inefficiently decide not to join the SSO, under the expectation that their technology becomes ex-post essential at which point they may negotiate larger payments from the SSO.

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1 Introduction

The general shift towards increasing complexity in many modern products in a number of industries has made the collaboration of firms that provide different expertise essential to bring a good to the market. An example of this phenomenon are smartphones, which now combine phones with email, cameras, video players, music players, calendars and organizational tools, online gaming, and GPS tracking systems, among other features. The proper functioning of the different components require that handset producers coordinate the innovation efforts of all the firms involved. Some coordination efforts, however, transcend the firm and apply to whole industries. Continuing with the case of mobile telephony, producers have to make sure that their handsets are interoperable with the wireless network, and this requires coordination on the network protocols and on some features of their devices.

This is a clear example of network economies, which have been studied in the economics literature since the 1980s, and for which standards are the obvious solution. Earlier papers, such as Farrell and Saloner (1985), study the inefficiencies that could arise when agents individually decide which technology to choose. Although to prevent these inefficiencies agents may coordinate in many different ways, Standard Setting Organizations (SSOs) have emerged as one of the most common arrangements.[1] Farrell and Saloner (1988) studies how standards are decided, and it shows that, compared to a *de facto* standard setting model, SSOs constitute a superior mechanism because although consensus may take longer to be reached, it tends to lead to fewer errors.[2]

[1]Under the umbrella term SSO we include informal industry consortia as well as more formal standards development organizations.

[2]Greenstein and Rysman (2007) illustrates the positive role that cooperation can play in standard setting, analyzing the 56K modem standard as a case study. In contrast to the common view of a standards war, the authors find that the 56K modem standardization process was not one of confident parties fighting to win a market. Instead, the two competing 56K modem camps fought over designs, with neither capturing enough support to "win" the market, until the International Telecommunications Union (ITU) eventually intervened so that the two options could be melded to create a marketable standard.

This paper studies how the licensing rules that SSOs establish affect innovation and participation of firms in a standard. We show that commonly proposed rules that suggest to reward patent holders according to the incremental value that a given technology contributes to the standard typically discourage firms from joining the SSO. As a result, less innovation is generated, reducing total welfare.

Most papers in the literature take a firm's participation in the SSO as given. When the participation aspect is considered at all, it is typically in the context of which standard setting mechanism to employ, cooperative or non-cooperative.[3] But even in these studies, the emphasis has generally been on the socially optimal form of determining a standard, not on any given firm's private decision-making process. Empirical work, however, suggests that participation is an important firm decision. Blind (2010) shows, for example, that firms that generate a higher proportion of their revenue from licensing tend to stay away from standardization processes. Rysman and Simcoe (2008) shows that the inclusion of a patent in a standard increases the patent's return, because it signals its value and influences future adoption of the patented technology. Consistent with the view that inclusion increases a patent's value, Simcoe et al. (2007) shows that patents disclosed in SSOs have higher litigation rates, particularly if these patents are assigned to small firms. They interpret this result as evidence of a platform paradox: While entrepreneurial firms rely on open standards to lower the fixed cost of innovation and market entry, entrepreneurial firms are also more likely to pursue an aggressive Intellectual Property (IP) strategy that can undermine the openness of a standard.

The decision of a technology contributor to participate in an SSO has many implications. IP holders are asked to disclose the patented inventions they hold and that

[3]Alternatively, Lerner and Tirole (2006) focuses on innovators choosing among SSOs trading off how appealing they are to users (and therefore, improving the probability that a firm's innovation will be adopted) and the concessions firms need to make to be certified by the SSO. They also study the welfare effects that this "forum shopping" entails. Chiao et al. (2007) shows that the predictions in Lerner and Tirole (2006) are consistent with empirical results. While addressing competition across SSOs is interesting to understand firm participation as well, it is beyond the scope of our initial analysis.

are essential for the standardized product to be marketed. This disclosure simplifies the process in which final manufacturers obtain a license of all the relevant technology. IP holders receive, in exchange, licensing fees that are meant to reward their investment.[4]

Due to the uncertainty regarding the technology and the standardization process, these licenses may not be negotiated ex-ante. Therefore, IP holders are only asked to commit to license their patents under Fair, Reasonable and Non-discriminatory (FRAND) terms. This lack of specific licensing terms has raised the concern that ex-post patent hold-up or other forms of opportunistic licensing by patent holders could occur if firms were able to exploit any market power they may have gained through their technology's inclusion in a standard. In particular, if the holder of patents on key technologies for a given standard refuses to license those patents on reasonable terms, SSO members can face significant switching costs in redefining or abandoning the standard. This is a standard hold-up problem (Farrell et al., 2007).

To alleviate this hold-up problem it has been suggested that SSOs (or courts or competition authorities) should impose certain restrictions on the licensing fees that their members can charge (Shapiro, 2001). Many papers have focused on establishing a reference for a *reasonable* royalty rate.[5] One of the most discussed proposals has been to cap a patent holder's licensing payments to the "incremental value" the patent contributes to the standard.[6] This proposal draws from the standard intuition in economic theory that goods should command a price premium corresponding to the total value they add over the next best alternative. Swanson and Baumol (2005) makes this proposal operational through the use of an ex-ante auction. Firms willing to have their technology included in the standard would bid ex-ante by offering a royalty rate. The firm that offered the lowest

[4]Of course, participation decisions for royalty-free standards and of implementers are interesting too but outside of the scope of this paper.

[5]For example, Mariniello (2001) suggests a four-point test that antitrust authorities could use in order to determine whether there is an indication that this is not the case.

[6]See for example Dolmans et al. (2007) or Farrell et al. (2007).

royalty (controlling for quality and licensing costs) would be included in the standard.[7]

Alternatively, Ganglmair et al. (2011) proposes a solution based on an ex ante commitment by innovators in the form of an *option-to-license* that manufacturers can exercise at a pre-specified price if they want to include their IP in the final product. Interestingly, they show that such an arrangement is superior to FRAND commitments backed by antitrust litigation as a way to mitigate the hold-up problem.

These different proposals usually abstract from the fact that an SSO is different from other vertical arrangements in that it is concerned with technologies that involve several complementary components and in which the participation decisions are endogenous to the revenue that firms expect to obtain. We show that both differences have important implications. Most papers associate the decision to innovate with the decision to participate. In practice, however, firms often choose to invest in research and development (R&D) even if their innovations are not included in the initial draft of a standard. This is due not only to the fact that the innovation may have other uses (for example, in another standard) but because it is often the case that continual R&D and innovation are required for the commercialization of a standard, especially when multiple generations of a standard are considered. Even without multiple generations, however, getting a standard commercialized can require research effort at multiple points in time, as new problems emerge during the development process (Layne-Farrar, 2010). Furthermore, to the extent that the value of a standard depends on the investments carried out by all firms, the decision to participate of an innovator feeds back into the participation and investment decision of other firms.

The model we present below shows that once we account for these two aspects an incremental value licensing rule emerges as a far less attractive tool for SSOs to prevent

[7] As they suggest, "the 'best' IP option will be able to command a license fee equal to incremental cost plus the difference in value between the best and the next-best alternatives" (Swanson and Baumol, 2005, pg.23). They define incremental cost as the costs per unit that patent holders incur as a consequence of licensing their patent.

patent hold-up. In particular, we find that the imposition of an incremental licensing rule reduces the R&D investment that a patent holder makes in relevant technologies and lowers the probability that it will join the SSO. This result is not specific to the incremental value rule. For example, it arises for other licensing rules like the benchmark licensing proposed in Lemley and Shapiro (2007). The reason is that patent holders would benefit from not committing ex-ante to the standard, anticipating that if their technology ever turned out to be better than the one accepted by the SSO there would be some room for a profitable ex-post negotiation. To ensure the patent holder's participation, then, we find that SSO members are able to and will be interested in increasing the licensing fees paid to the patent holder above the level dictated by the incremental value rule.[8]

The previous results are qualified depending on the level of complexity of the standard in the sense that it refers to multiple (and diverse) contributors. Due to the characteristics of a standard, R&D efforts of different firms are complementary, meaning that when a firm decides to join an SSO, its participation may trigger an increase in R&D expenditure of other firms, raising the overall success probability of the standard. Our results show that this countervailing force is important for simple standards (those with a very small number of complementary components). In complex standards, however, the feedback effect is weak or practically non-existent since the impact of R&D complementarities is diffused over a larger number of firms. In complex standards, therefore, the incentives for firms to stay out of the standard and avoid being limited by the incremental value rule dominates.

The overall picture indicates that licensing caps like the incremental value rule tend to reduce the incentives for firms to participate in cooperative standard setting since most standards can be qualified as complex. In the case of smartphones, standards are

[8] Of course, an alternative would be to reduce the proceeds that, by staying out of the SSO, the patent holder could negotiate ex-post for its technology. This change would imply a weakening of the patent statute. We find it implausible that the change could be circumscribed to this narrow hold-up situation, but would instead result in a reduction in the overall incentives to innovate.

promulgated by multiple SSOs around the globe, but the European 4G standard offers a case in point. The European Telecommunications Standards Institute (ETSI), an SSO involved in the development of a 4G wireless technology, is composed of a large number of participants contributing complementary technologies. Other standards include firms from diverse industries. This is the case of radio frequency identification tags (RFID or smart chips), which are used in tracking systems for shipping, payments cards, and even some passports. Among their promoters we find firms like 3M, Chrysler, France Telecom, HP, LG, Motorola, ThinkMagic, Wal-Mart, and Zebra Technologies.

The paper proceeds as follows. In section 2 we present the model. Sections 3 to 5 discuss the results of the model under a different number of firms. In section 6 we present some extensions of the model and robustness analysis. Section 7 concludes.

2 The Model

Consider a Standard Setting Organization that aims to promulgate a standard comprised of two different components, for which two new inventions are required. Denote these inventions as 1 and 2. We assume that innovation is a risky process that unfolds over time, such that R&D is only successful with some probability. The standard is valuable, however, only if both inventions are achieved. Denote the market value of a successfully developed standard as $v > 0$.[9] The members of the SSO obtain the value generated net of the total payments made to the firms that contribute the inventions comprising the standard.

There are two firms, 1 and 2, that can attempt inventions 1 and 2, respectively.[10] If a firm is successful it obtains a patent for its invention. Thus, we denote both firms as the *patent holders*. Each firm $i = 1, 2$ is successful in its R&D efforts with a probability ρ_i,

[9] Throughout the paper we abstract from the uncertainty regarding the value of the standard and we take v to be its expected value contingent on success. See also footnote 14.

[10] The case where more than one patent holder compete for the same innovation is left for future research.

independent across inventions. This success probability depends on the R&D investment expended by the firm.[11] In particular, achieving a probability of success ρ requires an expenditure

$$C(\rho) = \frac{1}{2}\rho^2.$$

Alternatively, the two inventions can be achieved with what we call a *default* technology. By this we mean that the invention can be implemented by SSO member firms uncovering an existing technology and adapting it to the standard under development. This discovery-adaption procedure requires a fixed expenditure $F > 0$ and is successful with a constant probability $s > 0$. Hence, if the SSO relies on the default technology for both inventions, the probability of success of the standard becomes s^2.

Finally, both the patented and the default technology may be pursued.[12] Notice that since the probability of success of the different technologies is independent, for high values of v (and low values of F) this might be optimal.

We also assume that a patent holder's invention can be used for other purposes, independently of whether it is accepted as part of the standard or not. These additional uses lead to profits $\pi > 0$. In order to focus on interior solutions for the firms' decisions we restrict the parameters so that $\pi + v \leq 1$. The main results, however, do not depend on this assumption.

Throughout the paper we consider the case in which the patented technology is superior to the default one but the standard might still be viable if patent holders do not participate, and the SSO needs to rely on the default technology. If the default technology works out (with probability s) then the non-participating patent holder will obtain no revenue from the SSO members, although, as long as the R&D is successful, it still

[11] This probability may also account for the risk that the patent protecting the invention is considered invalid.

[12] For simplicity, in most of the paper we assume that although both technologies can be researched only one can be finally included in the standard. This constraint might be motivated by the large cost of making all other components compliant with both technologies. In section 6.1 we show that our results are reinforced when this cost is small and both technologies can be included.

receives profits of π related to other uses of the invention. If the default technology fails, however, while the patented one is successful, the non-participating patent holder can negotiate with the SSO members and license its technology ex-post, unconstrained by any payment rule or other policies established by the SSO. We assume that in this case the patent holder can extract the entire surplus created by the standard, since it controls the only available technology required to bring the standard to market.[13]

The timing of the model is as follows. Initially, the SSO decides which technologies to pursue and establishes a payment scheme for the patent holders' inventions (a license). Patent holders simultaneously decide whether to participate in the standard or not. Patent holders then choose their R&D investment, $C(\rho)$. After uncertainty regarding the success of both technologies is resolved, each patent holder receives the corresponding licensing payments if it has decided to participate. Otherwise, an ex-post negotiation with the SSO ensues.

We focus mainly on one particular SSO payment rule that we denote as the *Incremental Value* (IV) license. This way of rewarding patent holders that contribute to an SSO aims to resolve the hold-up that can occur when a license is determined ex-post. This rule considers that a license should be established according to the ex-ante incremental contribution value of the chosen technology as compared to the next best alternative, measured at the stage in which other substitute technologies were available. In the context of this model, if invention 2 is achieved with probability ρ_2, the patent holder who contributes invention 1 receives, when the default technology is not included, a license payment

$$L_1^{IV}(\rho_1) = \rho_2\rho_1 v - \rho_2 s v = \rho_2(\rho_1 - s)v. \tag{1}$$

[13]This extreme assumption is consistent with the view of some practitioners that patent holders might enjoy too much bargaining power in ex-post negotiations in the context of an SSO and a hold-up problem might emerge unless an exogenous licensing benchmark like the one we discuss next is in place. Nevertheless, in section 6.2 we explore other allocations of bargaining power. We show that under some parameter combinations the results hold even when the patent holder has a very limited bargaining power.

That is, the inventor would be paid the (equilibrium) additional expected value contributed to the standard by invention 1, compared to the next best alternative.

In the case in which the SSO chooses to pursue both the default and the patented technology, the incremental value takes into account the increase in the probability of success due to its participation in the standard. In particular,

$$L_1^{IV}(\rho_1) = (1 - s)\rho_2\rho_1 v.$$

That is, the patented technology only makes a difference when the default technology for component 1 fails and the patented technology for both components succeeds.

In order to simplify the exposition, we start first by studying the case where there is only one possible patent holder. That is, whereas invention 2 can only be obtained with the default technology, invention 1 can be obtained either through investment in the default technology or new R&D. In the following section we discuss the case in which both patent holders may invest in new inventions.

3 A Single Patent Holder

We start by discussing the first best benchmark and we later compare it with the subgame perfect equilibrium of the game. We also characterize the optimal linear contract and compare it with the incremental value rule.

3.1 The First Best

The first best is characterized by summing the total surplus being generated by the development of the standard in a particular form (that is, with a particular combination of technologies) net of the costs of innovation required to reach that form. We need to consider three possibilities, depending on whether the first component is attempted only with the patented technology, with the default one or with both technologies.

When only the patented technology is developed for component 1, while technology 2 is attempted with the default technology, the optimal investment results from

$$\max_{\rho_1} \ \rho_1(sv + \pi) - C(\rho_1) - F,$$

or $\rho_1^{fb} = sv + \pi$. Quite intuitively, the optimal investment is increasing with the probability of success of the other (complementary) invention and the value of both the standard and the private profits that the patent holder can accrue outside of the standard.

The next assumption rules out situations where $\rho_1^{fb} < s$. As a result, licensing payments under the incremental value rule are guaranteed to be positive in the implementation of the first best.[14]

Assumption 1. $s \leq \frac{\pi}{1-v}$.

The second possibility is that both the default and the patented technology are pursued for component 1. In that case, the first best level of investment is characterized by

$$\max_{\rho_1} \ \rho_1\pi + (1 - (1 - \rho_1)(1 - s))sv - C(\rho_1) - F, \tag{2}$$

resulting in $\rho_1^{fb} = s(1-s)v + \pi$. Finally, a third possibility is that both default technologies are developed, in which case profits π are never accrued.

Depending on parameter values three possible allocations might be optimal. If F is very low, the default technology is efficient and it is pursued together with the patented one. If F takes an intermediate value, the patented technology is more efficient. Finally, if F is very large, developing the standard is not optimal in the first place, meaning that the investment in the second component should not be carried out. In that last case, the

[14] Our results remain unchanged if, instead, we assume that both the patented technology and the default one lead to success but there is uncertainty regarding the value of the standard, which can be either v_L or v_H with $v_H > v_L$. In that case, we require that v_H is more likely under the patented technology and that the quality obtained is independent across innovations. Defining $v \equiv v_H - v_L$ and $\pi \equiv \pi_H - \pi_L$ (where π_H and π_L denote the profits outside of the standard in each case) our results would translate to that case without variations.

patented technology should be used only to accrue the independent profits π. The next lemma characterizes the different thresholds.

Lemma 1. *The First Best is characterized by the following thresholds:*

1. *If* $F < \underline{F}$ *both the default and the patented technology should be developed for component* 1 *and the default technology for component* 2*,*

2. *if* $F \in [\underline{F}, \overline{F}]$ *the patented technology should be developed for component* 1 *and the default one for component* 2*, and*

3. *if* $F > \overline{F}$ *the patented technology should be used for component* 1 *and component* 2 *should not be developed.*

The critical values correspond to

$$\begin{aligned} \underline{F} &= s^2 v \left[1 - sv - \pi + \frac{s^2 v}{2}\right], \\ \overline{F} &= \frac{s^2 v^2}{2} + sv\pi. \end{aligned}$$

Notice that developing only the default technology for component 1 is never optimal, since the marginal cost of a small but positive investment in the patented technology is 0, but it leads to an increase in the probability of success.

To make the analysis non-trivial, we will assume throughout this section that $\overline{F} > \underline{F}$ and that F lies in the intermediate region. We later discuss briefly how the results change when the costs of the default technology are lower.

Assumption 2. $F \in \left[\underline{F}, \overline{F}\right]$.

3.2 Equilibrium under the Incremental Value Rule

We now turn to the private solution resulting from the use of the IV licensing scheme. As usual, we need to solve the game by backwards induction. Let us start with the situation in which the patent holder participates in the SSO, so that, under assumption 2, the default technology is not developed. We assume that the patent holder is being rewarded according to its *incremental value* which here translates into an ex-ante agreed license

$$L_1^{IV}(\rho_1) = s\rho_1 v - s^2 v = s(\rho_1 - s)v.$$

As a result, the patent holder will maximize

$$\max_{\rho_1} \; L_1^{IV}(\rho_1) + \pi\rho_1 - C(\rho_1),$$

leading to a success probability $\rho_1^{IV} = sv + \pi$ and profits $\Pi_1^{IV} = \frac{1}{2}(sv+\pi)^2 - s^2 v$. Thus, the incremental value rule leads to an efficient investment choice, which is precisely one of the main properties advocated for this licensing scheme.

Now consider the case in which the patent holder decides not to join the SSO and the SSO members attempt both default technologies. As pointed out before, patent holder 1 will only be compensated by the SSO if default technology 2 has been successfully identified and modified to fit the standard while 1 has not (so that the contribution of patent holder 1 is essential to the standard) and invention 1 has been successful. That situation occurs with probability $s(1-s)\rho_1$. In that case, the patent holder can extract all the surplus from the SSO. That is, the profit maximizing ex-post license that the patent holder will demand amounts to the whole value generated by the standard, $\hat{L}_1 = v$.

Anticipating this outcome, in the previous stage the patent holder chooses ρ_1 to maximize

$$\max_{\rho_1} \; s(1-s)\rho_1 \hat{L}_1 + \pi\rho_1 - C(\rho_1),$$

resulting in $\hat{\rho}_1 = s(1-s)v + \pi$ with profits $\hat{\Pi}_1 = \frac{1}{2}\left(s(1-s)v+\pi\right)^2$. It is important to notice that the patent holder in this case underinvests in ρ_1 compared to the first best or the situation where the firm participates and it is rewarded according to the incremental value rule. The reason is that, as opposed to the first best, the probability of being rewarded is now lower because the invention will be implemented as part of the standard only if the default technology fails. Thus, under the incremental value rule, the higher probability of being rewarded more than compensates for the lower licensing proceeds that the firm is promised when it participates in the standard setting efforts.

The main question, however, is whether in the subgame perfect equilibrium of the game the patent holder will join the SSO or not. The response to this question amounts to comparing patent holder profits under both situations, joining and not joining. The next proposition states that patent holder 1's profits are higher when it decides not to join the SSO, resulting in an inefficient investment allocation.

Proposition 2. *In the subgame perfect equilibrium of the game with only one patent holder and under the incremental value rule, the patent holder will obtain higher profits by not joining the SSO.*

This result is the main insight of this paper and the proof shows that it holds for any increasing and convex cost function, and not only for the quadratic specification we have assumed. As in most environments, the incremental value rule appears at first sight to be an appropriate way to provide reasonable compensation to firms that innovate contingent on their joining the SSO. However, the ex-ante competition between the patented and the default technology makes it appealing for a patent holder to stay out of the organization and to capture more than its marginal valuation ex-post once the invention becomes essential. This is, of course, detrimental to the SSO members. To see that, notice that when patent holder 1 joins the organization the surplus, W, can be computed as

$$W^{IV} = s\rho_1^{IV} v - L_1(\rho_1^{IV}) - F = s^2 v - F.$$

Because the patent holder obtains the incremental value of the innovation, the SSO obtains the profits that would have accrued when using the default technology 1 net of the cost of technology 2. Instead, if the patent holder decides to stay out, the surplus of the SSO, $\hat{W}$, becomes

$$\hat{W} = s(s + (1-s)\hat{\rho}_1)v - s(1-s)\hat{\rho}_1 v - 2F = s^2 v - 2F.$$

The difference corresponds to the fact that when the patent holder does not join the SSO, both the patented and the default technology are developed and an additional cost F is incurred by the SSO. As a result, the SSO members are worse off when the patent holder decides to stay out.[15]

Notice, however, that there is room for the SSO to agree ex-ante with the patent holder to a royalty above what the incremental value rule would prescribe in order to entice the patent holder's participation in the SSO.[16] In particular, the first best can be attained simply by increasing the licensing payment. The SSO could make an additional transfer (unconditional on ρ_1) that satisfied the initial participation constraint of the patent holder. This transfer should entice the patent holder to join the SSO but it should be low enough for the SSO not to rely on the otherwise inefficient default technology.

Corollary 3. *Any licensing payment $L_1 = \rho_1 sv + t$, with $t \in [\underline{F}, F]$ implements the first best allocation.*

The interpretation of this result is as follows. When the SSO pays a license with $t = F$, it is essentially indifferent between including the patent holder in the standard or not, since this is the difference between W^{IV} and $\hat{W}$. The reason is that it relinquishes all the additional surplus together with the cost savings generated by its participation (as opposed to the default technology).

At the other extreme, remember that $F = \underline{F}$ determines the critical value that in the first best makes the increase in the success probability generated by developing both

[15]Profits would have been $-F$ if the default technology for component 1 had not been attempted when the patent holder decided to stay out since in that case, success would have been associated with an ex-post license of v.

[16]This result is not due to the fact that $\hat{W} < 0$, since at least for low values of F (and large π) the SSO makes positive profits under the incremental value rule.

technologies equal to the increase in the development cost. However, notice that when the patent holder decides to stay outside the SSO, the total welfare generated is identical to what would have been achieved if both technologies had been developed inside the SSO. The reason is that the return $s(1-s)\rho_1 \hat{L}_1$ is precisely the marginal contribution of the patent holder in that case. For this reason, if the patent holder decides to participate it generates cost savings of at least $\underline{F}$. This must be the minimum additional payment that the patent holder should receive in order to internalize the effect that joining the standard has on society and determines the lower bound on t.

The previous discussion also allows us to analyze what would happen when Assumption 2 fails and $F < \underline{F}$. As shown before, in that case the first best would prescribe that both technologies for component 1 were pursued in the standard. Since the incremental value rule in that case prescribes the same compensation as the one the patent holder would obtain outside of the SSO, it would choose to participate.

Finally, notice that this optimal licensing payment differs from other proposals in the literature. As we point out in section 6.3 licensing schemes that make the payment that the patent holder receives a proportion of the incremental value related to its bargaining power, as discussed in Lemley and Shapiro (2007), will not only fail to induce participation but also to provide the proper incentives to invest in R&D.

In the next section we turn to the case where the two inventions can be obtained by a different patent holder. Although the basic forces discussed so far translate to that case, we show that new interesting insights appear in that situation. In a later section we analyze numerically the general case.

4 Two Patent Holders

As in the previous section, we start by characterizing the first best allocation and then compare it with what arises in equilibrium using different licensing schemes.

4.1 The First Best

Let's start by considering the case where it is efficient that only the patented technologies are developed. In that case, the first best results from

$$\max_{\rho_1,\rho_2} \pi\rho_1 + \pi\rho_2 + v\rho_1\rho_2 - C(\rho_1) - C(\rho_2).$$

The solution to this maximization leads to $\rho_1^{fb} = \rho_2^{fb} = \frac{\pi}{1-v}$. The total social welfare generated can be computed as $\frac{\pi^2}{(1-v)^2} > 0$.

Following the reasoning for the one patent holder case, alternatively, it might be optimal that the default technologies are also developed. In that case, the first best arises from

$$\max_{\rho_1,\rho_2} \rho_1\pi + \rho_2\pi + (1-(1-\rho_1)(1-s))\,(1-(1-\rho_2)(1-s))\,v - C(\rho_1) - C(\rho_2) - 2F. \quad (3)$$

Notice that, due to the symmetry and the complementarity of the two components it will never be optimal that two technologies are developed for one component and only one for the other. The reason is that an increase in the probability of success of, say, component 1 increases the productivity of developing the other technology for component 2.

The next lemma shows that, as in the previous case, only when F is low it is worthwhile to develop both default technologies, together with the patented ones.

Lemma 4. *In the first best, both the default and the patented technologies should be developed if*

$$F < \underline{F}' \equiv \frac{\pi^2 - 2\pi s^2 v + s^2 v + 2\pi s v}{2(1-(1-s)^2 v)} - \frac{\pi^2}{2(1-v)^2}.$$

Otherwise, only the patented technologies should be pursued.

As in the case of one patent holder, we will assume throughout this section that only the development of the patented technologies for the standard is optimal. In particular, we will replace Assumption 2 with the following one.

Assumption 3. $F \geq \underline{F}'$.

4.2 Equilibrium under the Incremental Value Rule

We start with the counterpart of the incremental value rule introduced in equation (1). With two identical patent holders, we need to discuss three cases, depending on whether (1) both firms join the standard, (2) none of them joins, or (3) one of them joins but the other decides to stay out. We proceed by studying the different cases separately in the next subsections and we later compare them in order to characterize the equilibrium of the game.

4.2.1 Both firms join the SSO

If both firms join the SSO, patent holder i obtains an expected licensing payment

$$L_i(v) = \rho_{-i}v(\rho_i - s),$$

where $-i$ denotes the component other than i. Thus, the optimal investment choice results from

$$\max_{\rho_i} \ \rho_{-i}v(\rho_i - s) + \pi\rho_i - C(\rho_i).$$

As in the one patent holder case, the (symmetric) equilibrium of this game leads to the efficient level of investment,

$$\rho_1^{IV} = \rho_2^{IV} = \frac{\pi}{1-v}.$$

Each firm obtains profits $\Pi^{IV} = \frac{\pi^2}{2(1-v)^2} - s\frac{\pi v}{1-v}$.

4.2.2 No firm joins the SSO

If no firm joins the SSO, given individual investment decisions ρ_i, for $i = 1, 2$, in the last stage of the game we need to consider four different outcomes. First, at least one of the inventions has not been successfully developed with either the default or the patented technology. Second, both components have been achieved using default technologies in the SSO. Third, only one default technology is available to the SSO (either because the other one was not researched or that research was unsuccessful) and the patent holder for the other invention was successful. Finally, only the patented technology was successful for each of the inventions.

In the first case, gross surplus is obviously 0 for the SSO. In the second situation, the gross surplus becomes v. The third case is similar to the situation with one patent holder, in which the SSO obtains 0 surplus, since the non-participating patent holder that faces no competition ex-post extracts a license equal to v. In the final case we assume that each patent holder can only extract profits equal to $\frac{v}{2}$.[17] Thus, the SSO obtains 0 profits here too.

Summarizing the previous discussion, when the two default technologies are chosen for the standard, the SSO will incur a development cost $2F$ and obtain a positive surplus v only when both of these default technologies are successful. In expected terms, the net surplus for the SSO becomes $s^2v - 2F$.

In this case, each patent holder $i = 1, 2$ will choose ρ_i to maximize

$$\max_{\rho_i} \; s(1-s)\rho_i v + (1-s)^2 \rho_{-i}\rho_i \frac{v}{2} + \pi\rho_i - C(\rho_i),$$

which leads to a symmetric equilibrium in which

$$\rho_1^* = \rho_2^* = \rho^* = \frac{s(1-s)\frac{v}{2} + \pi}{1-(1-s)^2 v},$$

and expected profits for each patent holder become

$$\Pi^* = \frac{\left[s(1-s)\frac{v}{2} - \pi\right]^2}{2(s^2v - 2sv + v - 1)^2}.$$

[17]This equilibrium can be obtained for example in an extensive form game with sequential offers where each patent holder has a probability $\frac{1}{2}$ of being chosen to be first. In that case, the willingness of the SSO to pay for the first license will be 0, since it anticipates that the second patent holder is pivotal and will demand v.

4.2.3 Only one firm joins the SSO

Finally, the third case with two patent holders corresponds to the situation where one of them, say firm 1, anticipating that the other firm joins the SSO, decides to opt out and try to obtain a higher licensing payment on the chance that the default technology for its invention is unsuccessful and, thus, it faces no competition ex-post. Firm 2 joining the SSO is rewarded according to the incremental value rule.

As in the previous case, in the last stage different scenarios must be considered depending on the success of the technologies for each of the components. From all the possibilities, patent holder 1 will obtain positive licensing profits only when its technology has been successful and its inclusion in the standard is essential. This occurs when innovation 2 has been successfully developed but the default technology for innovation 1 is not available. The probability of this scenario is $\rho_2(1-s)\rho_1$ and, as a result, firm 1 can extract a payment v from the SSO. Thus, patent holder 1 solves

$$\max_{\rho_1} \ \rho_2(1-s)\rho_1 v + \pi\rho_1 - C(\rho_1),$$

while patent holder 2 solves

$$\max_{\rho_2} \ (s + (1-s)\rho_1)v(\rho_2 - s) + \pi\rho_2 - C(\rho_2).$$

This last expression takes into account that, from the point of view of patent holder 2, the licensing payment is made as long as, for the other invention, either the default technology or the one sponsored by firm 1 succeeds.

The first order conditions lead to reaction functions

$$\begin{aligned} \hat{\rho}_1(\rho_2) &= \rho_2(1-s)v + \pi, && (4) \\ \hat{\rho}_2(\rho_1) &= (s + (1-s)\rho_1)v + \pi, && (5) \end{aligned}$$

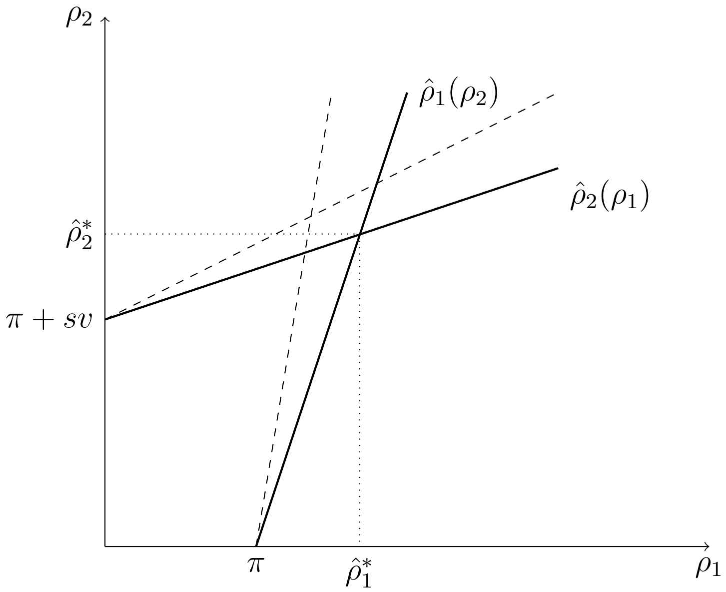

Figure 1: Reaction functions when only firm 2 joins the SSO. The dotted line represents the effect of an increase in s.

represented in Figure 1. Equilibrium probabilities of success can be derived as

$$\begin{aligned}\hat{\rho}_1^* &= \frac{\pi + \pi(1-s)v + s(1-s)v^2}{1-(1-s)^2v^2}, \\ \hat{\rho}_2^* &= \frac{\pi + (s(1-\pi)+\pi)v}{1-(1-s)^2v^2}.\end{aligned}$$

Observing the reaction functions, it is interesting to see the effect that an increase in s (the success rate of the default technology) has on the effort of both innovating parties. Regarding patent holder 2, for a given value of ρ_1, a higher probability of success of the default technology entices more investment due to the existing complementarities. An increase in s, however, has the opposite effect on the investment of patent holder 1 since its technology is less likely to be used. As the figure shows, the total effect on the equilibrium probabilities is a priory ambiguous.

Finally, we compute surplus for the SSO. The value v will be generated whenever innovation 2 has been successful and innovation 1 has been obtained either with the default or the patented technology. Notice, however, that in the latter case, the ex-post licensing deal extracts all the rents. Thus, the SSO will accrue a surplus only when the default technology for invention one is successful and the patented one for technology 2 is also successful. In that case, net surplus becomes

$$\hat{W} = s\hat{\rho}_2 v - L_2^{IV} - F = s^2 v - (1-s)\hat{\rho}_1 v(\hat{\rho}_2 - s) - F. \quad (6)$$

These profits might be positive if s is large and the difference in efficiency between the patented and the default technology is not very large.

4.3 The Equilibrium Decision to join the SSO

The three previous possibilities allow us to characterize situations where both firms join the SSO, one firm joins or none does. We will focus here on the effect of the incremental value rule on the incentives for both firms to join the SSO. In this sense, we study whether unilateral deviations are optimal for a patent holder or not, rather than to characterize the possible equilibria of the game.

The main difference with the case studied in section 3, where only one patent holder exists, is that now we need to take into account the effect that one patent holder's decision to join has on the investment committed by the patent holder of the complementary invention, which feeds back in the incentives for a firm to join the SSO in the first place.

Clearly, when $s = 0$ firms are indifferent between joining the SSO or not, since the incremental value of a technology also corresponds to the whole value that the innovation contributes. Investment in both situations will be identical. Increases in s do not have an effect on the investment of firms when both join the SSO, but they affect investments when one firm joins and the other does not. As the figure in the previous section shows, this effect is in general ambiguous. If increases in s lead to a decrease or a small increase in the investment of the firm that joins the SSO, the results of the previous section are preserved, and in equilibrium at least one firm will stay out of the SSO.

If instead, increases in s lead to a large increase in the investment of the firm that joins the SSO, the results might turn around, and an equilibrium may exist where both

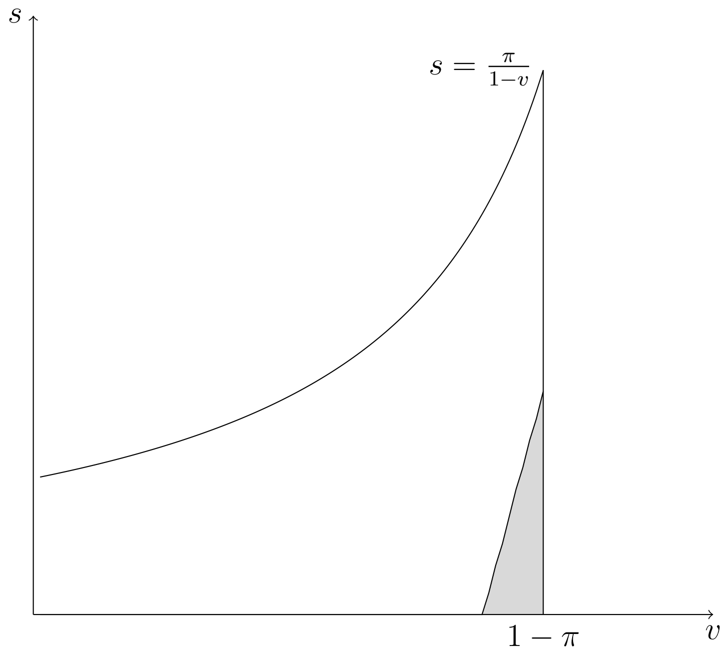

Figure 2: The decision to join the SSO for a value of $\pi = \frac{1}{4}$. The grey area corresponds to configurations of the parameters that lead to both firms joining the SSO.

firms join. As the next proposition shows, this is likely to occur when s is small.

Proposition 5. *If s is sufficiently small and $\pi+v$ are sufficiently close to* 1*, in equilibrium both firms will join the SSO.*

Numerical simulations like the one illustrated in Figure 2 suggest that, indeed, extreme values of s and π are the only ones for which both patent holders have the appropriate incentives to join the SSO. Notice that the only feasible configurations of parameters correspond to the area below the curve $s = \frac{\pi}{1-v}$ (satisfying Assumption 1) and to the left of $v = 1 - \pi$.

Finally, it is important to point out that, as in the case with only one patent holder, when the incremental value rule does induce firms to participate, the first best allocation can still be recovered by including an unconditional transfer of resources from the SSO to the innovators in the spirit of Corollary 3.

5 N Patent Holders

The previous section shows that the move from one patent holder to two leads to significant changes in the implications of the model. Both exercises are useful in order to gather intuition on the forces behind the results and the incentives for a firm to join an SSO. As the examples in the introduction show, however, SSOs typically comprise a large number of firms. In this section we provide a numerical exercise showing that, in fact, the larger the number of firms the fewer incentives to join any particular firm will have.

The previous section showed that a firm is willing to participate in the standard if it anticipates that its decision will spur a significant increase in the investment of other firms. The question we discuss here is whether the impact will be larger or smaller as the number of patent holders increases.

Suppose that there are N firms and all but firm 1 decide to join the SSO. The first order condition determining the level of investment of firm 1, ρ_1, and all others, that in a symmetric equilibrium is $\rho_i = \rho$ for $i = 2, ...N$, can be obtained from a generalization of (4) and (5), leading to

$$\begin{aligned}\hat{\rho}_1(\rho) &= (1-s)\rho^{N-1}v + \pi, \\ \hat{\rho}(\rho_1) &= (s + (1-s)\rho_1)\rho^{N-2}v + \pi.\end{aligned}$$

The Nash equilibrium of this game does not have an explicit solution for $N > 2$, so we need to rely on numerical results.

Figure 3 computes the elasticity of the total probability of success of other firms, ρ^{N-1} to changes in the investment of firm 1, ρ_1. As it can be seen from the picture, the effect on the elasticity of an increase in N is inversely U-shaped. For low values of N increases in ρ_1 have a large impact on the investment of the other firms, as the case in the previous section with two firms illustrates. When there are few firms, the sum of these efforts is large. As N increases, however, and the effort of more firms is necessary, the impact of an

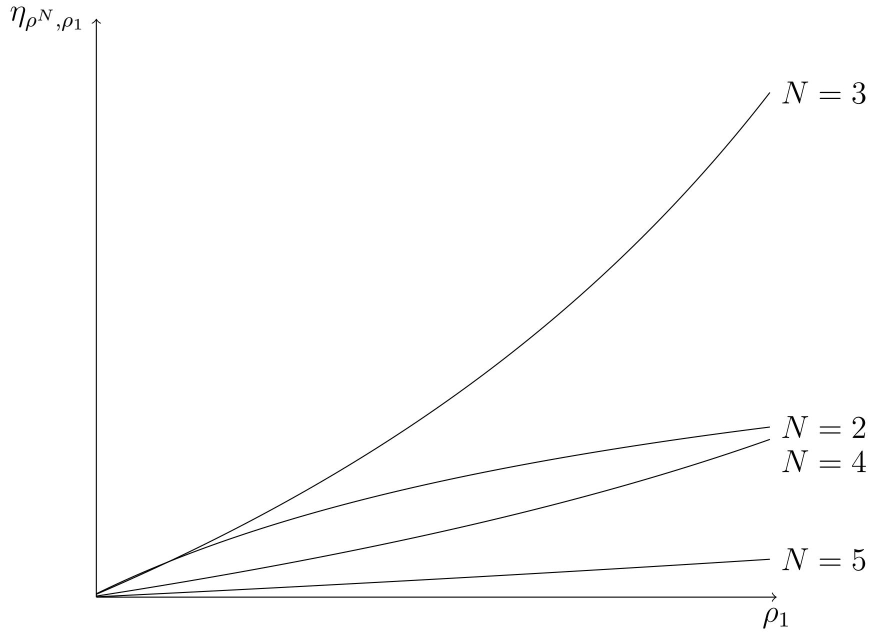

Figure 3: Elasticity of the total probability of success of other patent holders to a change in ρ_1 for various sizes of N. We have set $\pi = \frac{1}{4}$, $v = \frac{1}{2}$, $s = \frac{1}{4}$. We define the elasticity $\eta_{\rho^N,\rho_1} \equiv \frac{\partial}{\partial \rho_1}(\rho^{N-1})\frac{\rho_1}{\rho^{N-1}}$

increase in ρ_1 is diluted. Thus, the investment of each individual competitor is affected very little, resulting in a smaller aggregate effect.

These effects fade away when N increases, and for a larger SSO a patent holder anticipates that its participation will spur a very small change in the investment of the other parties. As a consequence, we can show that the region of parameters for which patent holders join the SSO when everybody else joins disappears as the number of patent holders increase, reverting to the result obtained in the one patent holder case.

6 Robustness Analysis

In this section we discuss the extent to which the results hinge on our basic assumptions and the effect of relaxing some of them.

6.1 Substitute Technologies in the Standard

In the previous discussion we have allowed for the possibility that the SSO sponsors the development of more than one technology. Implicitly, however, we have assumed that if both technologies were successful only one would be chosen for the standard. This is the typical behavior of SSOs and it is due to the fact that integrating more technologies may raise the cost of producing a good that complies with the standard. For example, if two technologies can be used to produce component 1, and they represent different ways of achieving a similar goal, the second component needs to be prepared to interact with either of the two technologies. In some respects, the cost of this additional requirement explains the need to have a standardization process for that product in the first place.

Nevertheless, sometimes SSOs may choose to include two (or more) substitute technologies in the standard.[18] Our model can accommodate this possibility by assuming that if the SSO integrates more than one technology, an additional amount k needs to be spent. This cost is incurred only if both technologies are successful. In order to discuss the effects of this assumption, in the remainder of this section we focus on the case where only one patent holder exists.

When incorporating two substitute technologies in the standard is costly, it is easy to see that the first best should never include them. Instead, the first best should prescribe that the patented technology is included if and only if the default one fails or vice versa. The welfare level achieved in the first best, thus, will coincide with the results obtained in the previous sections.

For this reason, in this section we use as a benchmark the case in which the SSO commits ex-ante to accepting both technologies if they are successful. In this case, it is

[18] For example, two radio transmission technologies were chosen for the European 3G mobile standard UMTS/WCDMA.

easy to see that the optimal level of investment in the patented technology 1 arises from

$$\rho_1^* = \arg\max_{\rho_1} \ \rho_1\pi + (1-(1-\rho_1)(1-s))sv - C(\rho_1) - F - s^2\rho_1 k,$$

where the difference with respect to (2) arises from the last term that accounts for the additional cost of adapting both technologies to the standard when both succeed. It is easy to see that the optimal policy requires a lower investment in the patented technology 1,

$$\rho_1^* = \pi + s(1-s)v - s^2 k, \tag{7}$$

since now a success of the patented technology when the default one is also successful is associated with the additional cost k. The next result characterizes the optimal decision of an SSO and it is the analog of Lemma 1 in this case.

Lemma 6. *When integrating more than one technology in the standard is costly, the optimal decision of an SSO, when it commits to incorporate successful technologies that are accepted ex-ante, is characterized by the following thresholds:*

1. *If $F < \underline{F}(k)$ both the default and the patented technology should be developed for component one, and the default technology for component* 2*,*

2. *if $F \in [\underline{F}(k), \overline{F}]$ the patented technology should be developed for component* 1 *and the default one for component* 2*, and*

3. *if $F > \overline{F}$ the patented technology should be developed for component* 1 *and component* 2 *should not be developed.*

The critical values correspond to

$$\begin{aligned} \underline{F}(k) &= \begin{cases} s^2v + \frac{s^4(v+k)^2}{2} - (\pi+sv)s^2(v+k), & \text{if } k < \frac{\pi+s(1-s)v}{s^2} \\ s^2v - 2F & \text{otherwise.} \end{cases} \\ \overline{F} &= \frac{s^2v^2}{2} + sv\pi, \end{aligned}$$

with $\underline{F} < \overline{F}$ under Assumption 1 and $\underline{F}$ is weakly decreasing in k.

It is easy to verify that for $k = 0$ the thresholds coincide with those in Lemma 1. As k increases, however, the region for which using only the patented technology is optimal expands, but the optimal investment decreases. In fact, when k is sufficiently high no investment in the patented technology ought to be undertaken. The threshold value in the lemma corresponds to the level of k that makes ρ_1^* equal to 0 in (7).

In the equilibrium under the incremental value rule, however, the cost of incorporating both technologies does not affect the results in the relevant region, that is, when $\underline{F}(k) \leq F \leq \overline{F}$. The reason is that when the patent holder decides to stay out of the SSO, the technology is only accepted as part of the standard when the default technology fails, and therefore, the cost k is not incurred. Therefore, incorporating this realistic feature reinforces the results of the basic model to the extent that it increases the range of values of F for which the distortion is likely to occur.

6.2 Ex-post Bargaining Power

When modeling the participation decision of firms in the standard, we have assumed that the outside option gives all the ex-post bargaining power to the patent holder in case its technology becomes essential. Of course, one may argue that the reason why something like the incremental value rule has been proposed is precisely in order to tame the power that the patent holder would otherwise have, and this should be the relevant case.

Nevertheless, this assumption certainly plays a part in our results. In this section we show, however, that the effect on the firm's participation under the incremental value rule remains unchanged as long as this bargaining power is not too low. We also discuss how this threshold bargaining power changes with the parameters of the model. In order to simplify the exposition we focus again on the one patent holder case.

We assume now that ex-post the patent holder can claim only a proportion α of the total value generated by the standard when its participation is essential. In other words, $\hat{L}_1 = \alpha v$. Thus, the new probability of success of the patent holder and its profits correspond now to $\hat{\rho}_1 = s(1-s)\alpha v + \pi$ and $\hat{\Pi}_1 = \frac{1}{2}\left(s(1-s)\alpha v + \pi\right)^2$.

Under the incremental value rule, the patent holder will decide to join the SSO to the extent that $\Pi_1^{IV} \geq \hat{\Pi}_1$, or

$$\alpha \leq \alpha^*(s, \pi, v) \equiv \frac{\left[(sv+\pi)^2 - 2s^2 v\right]^{1/2} - \pi}{s(1-s)v}.$$

This critical value, consistent with Proposition 2, can be shown to satisfy $\alpha^*(s, \pi, v) < 1$. The next proposition describes the corresponding comparative statics.

Proposition 7. *The minimum level of bargaining power for which firms are indifferent between participating in the standard or not is increasing in π and v.*

Thus, the main result of the paper should hold for lower bargaining power to the extent that either π or v is sufficiently low and F still satisfies assumption 2. The reason is that the difference in investment between joining the SSO or not is lower when these profits are smaller, and the return from staying outside of the SSO does not decrease as much in that case. In particular, α^* might be lower than $\frac{1}{2}$, corresponding to equal bargaining power between the patent holder and the SSO, if, for example, s is close to 1/3 and $\pi = v = 0.4$.

6.3 Other Incremental Value Benchmarks

We now discuss two alternative interpretations of the incremental value rule. The first one is based on Lemley and Shapiro (2007). The second involves, in the multiple patent holders case, the way the complementarities change investment when the other innovation is obtained with the default or the patented technology.

Regarding the first, Lemley and Shapiro (2007) is an influential paper that studies how court injunctions and royalty stacking might have the potential to raise the royalty rates that patent holders may ask of users of the technology, above a certain benchmark level.

Their benchmark suggests that in one stage negotiations the royalty rate we would expect to see would be equal to $L^{LS} = b\theta v$, where v is the incremental value of the technology, θ is the probability that the patent is considered valid by a court, and $b \in [0,1]$ is the bargaining power of the patent holder. Even though Lemley and Shapiro admit that this should not necessarily be considered the "right price" for a technology, this model has captured considerable attention. Here we study what distortions we would expect to emerge if SSOs implemented such a rule or, alternatively, if innovators anticipated that they would be rewarded according to it. We will do so in the context of only one patent holder and assuming, for simplicity, that $\theta = 1$. Thus, in the context of our model, the previous proposal will result in

$$L_1^{LS}(\rho_1) = s(\rho_1 - s)bv.$$

Clearly, profits for patent holder 1 when it decides to stay out of the SSO, remain unchanged compared to the benchmark situation, and are equal to $\hat{\Pi}_1 = \frac{1}{2}\left[s(1-s)+\pi\right]^2$. Instead, when the firm joins the SSO, the success probability becomes $\rho_1^{LS} = sbv + \pi \leq \rho_1^{fb}$ and profits are $\Pi_1^{LS} = \frac{1}{2}(sbv+\pi)^2 - s^2bv$. Interestingly, as the next proposition shows, these profits might not be monotonic in b. They are, however, lower than $\hat{\Pi}_1$ and, thus, they will not entice participation in the SSO.

Proposition 8. *In the subgame perfect equilibrium of the game with only one patent holder and under the Lemley and Shapiro rule, contingent on participation*

1. *the probability of success is lower than in the first best, and*

2. *profits are increasing in b if and only if $b \geq \bar{b}$ where $\bar{b} \equiv \frac{s-\pi}{sv} < 1$, but*

patent holder 1 *obtains higher profits by not participating in the SSO. Thus, the benchmark in Lemley and Shapiro (2007) does not induce firm participation.*

The previous proposition points out that this rule is likely to lead, in our setup, to more distortions than a pure implementation of the incremental value rule. In particular, while in equilibrium it does not entice firm participation in the SSO, in case this participation occurred it would lead to a lower level of innovation, hurting the probability of success of the standard.

We now turn to another interpretation of the incremental value rule. A possible concern in the two (or more) patent holders case is that our expression for the incremental value rule in equation (1) assumed that when patent holder 1 decided between participating or not the investment of patent holder 2 would be the same regardless of this decision. In equilibrium, however, we know that because of the complementarity between the investment of both firms this is unlikely to be the case. If we take that effect into account, equation (1) results in

$$L_1^{IV}(\rho_1) = \rho_2 \rho_1 v - \tilde{\rho}_2 s v_1,$$

where $\tilde{\rho}_2$ is the investment that patent holder 2 would make had patent holder 1 decided not to join the SSO.

As pointed out before, due to the complementarity between investments, this licensing payment is likely to be larger than the one used in the previous sections of the paper. Nevertheless, Figure 4 shows that, although this change increases the range of values for which the incremental value induces participation and with it the optimal level of investment, qualitatively the results are preserved.

7 Concluding Remarks

Patent hold-up and opportunistic licensing within cooperative standard setting organizations have received considerable attention and a number of rules and policies have been suggested to curb these problems. In this paper, we have considered one of the most

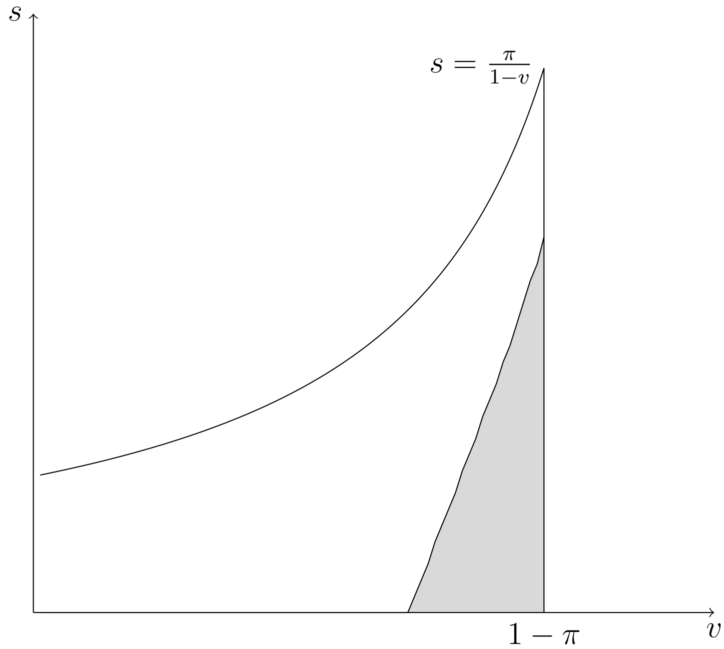

Figure 4: The decision to join the SSO for a value of $\pi = \frac{1}{4}$, under the alternative licensing rule. The grey area corresponds to configurations of the parameters that lead to both firms joining the SSO.

popular suggestion: capping patent holder licensing fees at the incremental value the patented technology contributes to the standard. The idea behind this cap would be to limit a patent holders' licensing fees to the level that could be obtained ex-ante, before the standard is fully developed and when the patented technology may compete with other alternatives.

The incremental value rule rests on two implicit but pivotal assumptions. First, all R&D has been conducted and the innovations are available for use in the standard. Second, all patent holding firms have chosen (or necessarily will choose) to join the cooperative SSO. We developed a model that illustrates the effect of relaxing these two assumptions. In the single patent holder case, we showed that if the patent holder joins the SSO, the imposition of an incremental value licensing cap leads to an efficient R&D investment choice. However, when free to choose, the patent holder will not join an SSO with an incremental value rule in place and as a result its investment will be sub-optimal.

Instead of joining, the patent holder's best strategy can be to remain outside of the SSO on the chance that the SSO will require the patented technology to complete the standard (i.e., the substitute default technology fails), in which case the patent holder can charge an unconstrained ex-post fee equal to the entire value of the standard. In other words, by imposing an incremental value licensing fee cap, the SSO may actually increase the odds that its licensing members face patent hold-up.

Expanding the analysis to two patent holders illustrates the dependencies that can be present among innovative firms. A particular patent holder's decision to join the SSO is affected by whether the other patent holder joins, the probability that the other patent holder will be successful in its R&D thus enabling a standard to emerge, as well as the probability that the replacement default technology will be successful thus rendering the firm's patented technology irrelevant. Using numerical methods, we find that it is only under very narrow circumstances that both patent holders will have appropriate incentives to join an SSO that has imposed an incremental value licensing fee cap. In particular, the alternative default technology must be of very little relevance (in the sense that the probability of success is small) and the value of the standard product compared to the profits that the patent holder could obtain by itself has to be large.

As the number of patent holding potential SSO participants increases, however, the interplay between complementary patent holders fades. In the more realistic case of $N > 2$ patent holders, any given patent holder will expect only a small change in the investment of the other parties contingent on it joining the SSO. Hence, without the countervailing investment effect, the patent holder will choose not to join an SSO with an incremental value licensing cap in place, just as in the single patent holder case.

Of course, our stylized model assumes away many important aspects of the institutional arrangements in SSOs. Our robustness analysis has discussed a few, such as the optimality of developing more than one invention for the same technology or different allocations of the bargaining power. Observe, however, that the availability of profits outside of the SSO is not the driving force behind a patent holder's decision not to join an SSO. Indeed, our results hold for π arbitrarily small.

An important aspect that this paper assumes away is the distinction between different members of the standardization effort. In practice, as the examples in the introduction make clear, some firms are technology contributors to the standard, others are implementers of the standard, and some firms are both. Their incentives to participate are obviously different. Our model emphasizes the participation distortions that might affect technology contributors, but integrated firms may also face other trade-offs. For example, they might attempt a *de facto* standard in competition with the SSO if they hold enough of the technology (or can make enough licensing deals on their own), they might join a competing SSO if one existed, or they might lead a separation faction to pressure other SSO members, as discussed in DeLacey et al. (2006).

Also importantly, firms might contribute technology to different SSOs that might create independent or competing standards. The existence of these different organizations might alter development and participation decisions by endogeneizing the outside profits of a patent holder, π. That parameter could thus be interpreted as a function comprising these different sources of profits.

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A Proofs

Here we prove most of the results in the paper.

Proof of Lemma 1: Let's denote as $S_{i,j}$ the social welfare generated when a set that includes the patented (P) and/or the default (D) technology is used for component 1 and 2, respectively. We consider four possibilities:

- The two default technologies are developed,

$$S_{D,D} = s^2 v - 2F.$$

- The patented technology and the default technology are developed for component 1 and 2, respectively,

$$S_{P,D} = \frac{(sv + \pi)^2}{2} - F.$$

- Both the default and the patented technology are developed for component 1 and the default one for component 2,

$$S_{PD,D} = s^2 v + \frac{(\pi + s(1-s)v)^2}{2} - 2F.$$

- Only the patented technology for invention 1 is developed. Social welfare becomes $\frac{\pi^2}{2}$.

First, notice that the first possibility is dominated by the third option, namely developing both the default and the patented technology for component 1.

Comparing the three remaining possibilities we obtain the thresholds stated in the lemma.■

Proof of Proposition 2: Consider any continuous differentiable, increasing, and convex cost function $C(\rho)$. The postulated quadratic cost function obviously satisfies these assumptions. Define the function

$$\phi(\lambda) \equiv \max_{\rho_1} \; [\lambda(1-s)\rho_1 + (1-\lambda)(\rho_1 - s)]\, sv + \pi\rho_1 - C(\rho_1). \tag{8}$$

Notice that $\Pi_1^{IV} = \phi(0)$ and $\hat{\Pi}_1 = \phi(1)$. Hence, a sufficient condition for $\hat{\Pi}_1 \geq \Pi_1^{IV}$ is that $\phi(\lambda)$ is increasing in λ. The derivative can be computed as

$$\frac{d\phi}{d\lambda} = (1 - \rho_1^*(\lambda))s \geq 0,$$

where $\rho_1^*(\lambda)$ is the maximizer of (8). Notice that $\hat{\Pi}_1 > \Pi_1^{IV}$ if $\rho_1^*(1) < 1$.■

Proof of Lemma 4: As stated in the text, when only the patented technologies are developed it is easy to show that the optimal level of investment results in $\rho_1^{fb} = \rho_2^{fb} = \frac{\pi}{1-v}$ and social welfare $W_{P,P}^2 = \frac{\pi^2}{(1-v)^2}$.

If the default as well as the patented technologies are developed, the optimal investment arises from (3) and results in

$$\rho_1^{fb} = \frac{\pi + (1-s)sv}{1-(1-s)^2 v}.$$

and social welfare

$$W_{PD,PD}^2 = \frac{\pi^2 - 2\pi s^2 v + s^2 v + 2\pi sv}{1-(1-s)^2 v} - 2F.$$

Notice that if two technologies are developed for one of the components, say component 1, it is also optimal to develop the two technologies for the other component, component 2. The reason is that not developing the patented technology 2 is equivalent to choosing $\rho_2 = 0$ in equation (3) which, as shown above, cannot be optimal.

Comparing the expressions for $W_{P,P}^2$ and $W_{PD,PD}^2$ leads to the condition stated in the lemma.■

Proof of Proposition 5: It is immediate when $s = 0$ that $\hat{\rho}_1^* = \hat{\rho}_2^* = \rho^{IV}$. Thus, the probability of success and the ensuing profits are the same. In order to prove the result it is enough to show that the derivative of the profit function of the firm that does not join the SSO, firm 1 in the previous section, is larger than when it joins.

Regarding the second,

$$\frac{\partial \Pi^{IV}}{\partial s} = -\pi v.$$

The effects of s on the profits of firm 1 when it does not join the SSO can be expressed as

$$\frac{\partial \hat{\Pi}}{\partial s} = -\hat{\rho}_1^* v \left(\hat{\rho}_2^* - (1-s)\frac{\partial \hat{\rho}_2{}^*}{\partial s} \right).$$

The expression in brackets, evaluated at $s = 0$ leads to

$$\left(\hat{\rho}_2^* - (1-s)\frac{\partial \hat{\rho}_2{}^*}{\partial s} \right)\Bigg|_{s=0} = \frac{\pi}{1-v} - \frac{(1-\pi)v}{1-v^2} + \frac{2\pi v^2}{(1-v^2)(1-v)}$$

which is increasing in π. Thus we can compute the difference in the derivatives when $s = 0$ and $\pi + v = 1$ as

$$\left(\frac{\partial \hat{\Pi}}{\partial s} - \frac{\partial \Pi^{IV}}{\partial s} \right)\Bigg|_{\{s=0,\pi+v=1\}} = v^2 + \frac{v^2}{1-v^2} > 0.$$

By continuity, the positive sign will also hold for $\pi + v$ close to 1 and s close to 0.■

Proof of Lemma 6: When only the patented technology is included in the standard, social welfare becomes

$$\frac{(sv+\pi)^2}{2} - F,$$

whereas if both the default and the patented one are included social welfare becomes

$$s^2 v + \frac{(\pi + s(1-s)v - s^2 k)^2}{2} - 2F.$$

Comparing these two options leads to the threshold $\underline{F}(k)$. The other threshold is obtained in an analogous way as in Lemma 1.■

Proof of Proposition 7: The threshold value of α can be obtained from

$$f(\alpha, v, s, \pi) \equiv (s(1-s)\alpha v + \pi)^2 + 2s^2 v - (sv+\pi)^2 = 0$$

Notice that

$$\begin{aligned}
\frac{\partial f}{\partial \alpha} &= 2(s(1-s)\alpha v + \pi)s(1-s)v > 0, \\
\frac{\partial f}{\partial \pi} &= 2sv(\alpha(1-s) - 1) < 0.
\end{aligned}$$

Using the implicit function theorem we obtain the stated result for π.

Regarding v, notice that

$$\begin{aligned}
\frac{\partial f}{\partial v} &= 2s\{(1-s)\alpha\,[s(1-s)\alpha v + \pi] + s - (sv+\pi)\} \\
\frac{\partial^2 f}{\partial^2 v} &= 2s^2(1-s)^2\alpha^2 - 2s^2 < 0.
\end{aligned}$$

so that $\frac{\partial f}{\partial v}$ is decreasing in v.

We need to consider two cases. Suppose that $s > \pi$. Define $\underline{v}$ as the value of v for which $\alpha^* = 0$. There are two possibilities, $v = 0$ and $2\frac{s-\pi}{s} > 0$. We rule out the first root since for the range $\left(0, 2\frac{s-\pi}{s}\right)$, $\alpha^* < 0$. Thus, $\underline{v} = 2\frac{s-\pi}{s} > 0$. We can, therefore, conclude that

$$\frac{\partial f}{\partial v} < \left.\frac{\partial f}{\partial v}\right|_{\underline{v}} = 2s^2 - 2s(2(s-\pi)+\pi) = -2s(s-\pi) < 0.$$

If instead $s < \pi$, $\alpha^* > 0$ for all values of v. Notice that under $s < \pi$, the second degree polynomial in α in $\frac{\partial f}{\partial v}$ is negative if and only if $\alpha \in [0, \overline{\alpha})$ defined as

$$\overline{\alpha} = \frac{-\pi + (\pi^2 + 4sv(sv + \pi - s))^{\frac{1}{2}}}{2(1-s)sv},$$

and it can be shown that $\alpha^* < \overline{\alpha}$ if $\pi > s/2$. Thus, $\frac{\partial f}{\partial v} < 0$.■

Proof of Proposition 8: Patent holder 1 maximizes the expression

$$\Pi_1^{LS}(b) = \max_{\rho_1} \; L_1^{LS}(\rho_1) + \pi\rho - C(\rho_1),$$

which leads to $\rho_1^{LS} = sbv + \pi \leq \rho_1^{fb}$. Notice that

$$\begin{aligned} \frac{\partial \Pi_1^{LS}}{\partial b} &= s(\rho_1^{LS} - s)v = sv(sbv + \pi - s), \\ \frac{\partial \Pi_1^{LS}}{\partial b} &= s^2 v^2. \end{aligned}$$

Thus, the profit function is concave in b. Furthermore, profits are minimized at $b = \hat{b} = \frac{s-\pi}{sv}$ and are maximized at either $b = 1$ or $b = 0$. If $b = 1$ the results in Proposition 2 apply. If $b = 0$, profits are equal to $\frac{\pi^2}{2}$ which are obviously less than $\hat{\Pi}_1$. ■