

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 patented 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 ask for fees equal to the full value the standard creates without constraint by the SSO.

1 Introduction

The general shift towards increasing complexity in many modern products has made the collaboration of firms that provide different expertise essential to bring a good to the market in a number of industries. An example of this phenomenon are smart phones, which now combine phones with email, cameras, video players, music players, calendars and organizational tools, online gaming, and GPS tracking systems, among other features. Similarly, home movie systems require compatibility between the movie player, the movie

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format (e.g. DVD, Blu-Ray), and often a projector and a separate sound system. The Internet would not even exist without cooperation amongst numerous firms and numerous nations. Other products less visible to end consumers nonetheless require coordination across many diverse partners, such as radio frequency identification tags (RFID or smart chips) which are used in tracking systems for shipping, payment cards, and even some passports. As more and more goods either combine features (as in the case of smart phones) or develop widely diverse applications (as RFID tags do) collaboration across firms and even across industries will only become more prevalent.

Although this collaboration can be articulated in many different ways, Standard Setting Organizations (SSOs) are one of the more common arrangements.¹ Within SSOs developers contribute their technologies and collaborate with final manufacturers in the design and integration of all the different parts of the product at hand.

The many benefits of the resulting cooperative standard setting process have been well recognized over the past few decades. Among them are the promotion of price competition among firms; the compatibility and interoperability of complex products that span several industries, or several distinct niches within a given industry; the realization of network effects; and often increased commercial markets.

However, while more firms are participating in more standard setting efforts across more industries today than ever before, the fact remains that participation in such efforts is voluntary. Firms can and do choose to opt out. In this paper we consider factors that can affect a firm's decision to join a cooperative standard setting organization. In particular, we examine the role that intellectual property licensing rules can have on a patent holding firm's standard setting participation decisions.

Firms participating in an SSO are asked to disclose the patented inventions they hold that may be necessary for the standardized product to be marketed. This disclo-

¹Under the umbrella term SSO we include informal industry consortia and more formal standards development organizations.

sure simplifies the process in which final producers obtain a license of all the relevant technology. An important concern, however, is the possibility of ex-post patent hold up or other forms of opportunistic licensing by patent holders that may be able to exploit market power 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 re-defining or abandoning the standard. For this reason, 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). One approach would be to cap a patent holder's licensing payments at the "incremental value" the patent contributes to the standard.² This proposal draws from the standard intuition in economic theory that goods should command a price premium corresponding to the value they add over the next best alternative.

In this paper, we consider the implications that such an incremental value rule would have on innovators' decisions to invest in research and development (R&D) in the first instance and also on their decision to join a cooperative SSO. We find that while the incremental value rule has intuitive appeal for patent licensing within SSOs, it starts from two strong presumptions: 1) that all innovations required for the standard (or for a particular component of the standard) have already been developed and 2) that all innovators have already chosen to participate in the SSO. Neither of these conditions need be met in practice, however. First, 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 – think of the evolution of in-home movie playback equipment, from reel-to-reel players to analog VHS tape players, digital DVD players and, most recently, high definition Blu-Ray players. Even without multiple gener-

²See for example Dolmans et al. (2007) or Farrell et al. (2007).

ations, 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). Second, SSO participation is voluntary, so the risk that a firm with important technologies for a standard abstains from participating is of genuine concern.

The model we present below shows that once we account for these two dynamic aspects an incremental value licensing rule emerges as a far less attractive tool for SSOs to prevent 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. The reason is that patent holders would benefit from not committing ex-ante to the standard, anticipating that if their technology 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.

We also explore how the incentives for a firm to participate change as a function of the complexity of the standard, in the sense that it refers to multiple (and diverse) contributors. Consider, for example a couple of the standards mentioned at the beginning of this article. Smart phone standards are promulgated by multiple SSOs around the globe, but the European 4G standard offers a case in point. The SSO involved in the development of 4G wireless is the European Telecommunications Standards Institute (ETSI). Some ETSI members, such as Ericsson and Nokia, are large European-based firms that conduct R&D and hold many relevant patents, but that earn their revenues chiefly downstream through the manufacture and sale of smart phone handsets. Qualcomm, a relatively smaller U.S.-based firm, also conducts substantial R&D, holds relevant patents, and has a subsidiary that designs and sells chipsets for inclusion in smart phone handsets. Qualcomm does not make handsets itself, though, and thus has some revenues from an intermediary mar-

ket but no downstream revenues. Other North American firms, such as Interdigital and Wi-Lan Inc., are pure research firms and conduct no manufacturing at all. Others, such as Asian firms Kyocera and LG Electronics, have little R&D, have contributed no IP to the 4G standard, and instead focus on manufacturing and selling handsets downstream. Still other participants, such as Sweden's Telia AB or America's Digital Theater Systems, are relatively smaller niche players, focusing on a narrow geographic area or a product peripheral to the standard. As this one example shows, even within a given industry (wireless telecommunications), the array of firms involved can be both extensive and diverse, which complicates the cooperative process of standard setting. That task can be even more challenging when the standard at hand involves firms from numerous and diverse industries, as the RFID standard does: 3M, Chrysler, France Telecom, HP, LG, Motorola, ThinkMagic, Wal-Mart, and Zebra Technologies have all been active in RFID standard setting. Standards such as those for smart phones and RFID clearly qualify as "complex".

It turns out that the incremental value rule provides a lure to participating in less complex standards, and only under some specific circumstances. The reason is that 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 success probability of the standard. This increase may compensate for the lower licensing proceeds from participating in the standard with an incremental value rule. This countervailing force, however, is less likely to operate for more complex standards, where the impact of R&D complementarities is diffused over a larger number of firms.

The paper proceeds as follows. In section 2 we review the relevant literature on standard setting, highlighting the contribution that the analysis developed here provides. In section 3 we present the model. Sections 4 to 6 discuss the results of the model under a different number of firms. In section 7 we present some extensions of our analysis, con-

sidering the special case of multiple substitute technologies chosen for a single standard. Section 8 concludes.

2 The Relevant Literature

The economics literature on standards started in the 1980s, and it has lately expanded into the study of the licensing rules that organizations dedicated to drafting standards use to reward the firms that contribute their knowledge. The earlier papers, such as Farrell and Saloner (1985), studied the coordination problems that could arise when agents can decide to switch to a later, superior technology. They find that without complete information standards exhibit excess inertia – that is, participants fail to coordinate to move to the superior technology, even when agents are unanimous in their preferences for change. 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.³

Recent papers, however, have emphasized the negative effects of SSOs which may arise when collaboration among firms turns into collusion. Shapiro (2001) deals with this issue and shows that firms may agree on a standard different from the one that would emerge under a standard war in the market. He finds that although both the cooperative standard setting model and the standard war process generate competition, this competition occurs at different stages. In the case of standards wars, competition occurs ex ante while cooperative SSOs lead to ex post competition among producers. Finally, Belleflamme

³Greenstein 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.

(2002) points out that when a formal standard and an informal one compete for adoption, the type of negotiation the firms engage in has important consequences. In particular, the ability to conduct verbal negotiations leads to an excessive adoption of the formal standard, while unilateral adoption excessively favors the de facto standard.

Another strand of the literature has focused on patent licensing aspects within SSOs. Farrell et al. (2007) discusses the possibility of ex post patent hold up within an SSO. These authors conclude that some restrictions on patent holding SSO members' behavior, mainly through patent reform, aimed at limiting ex post hold up are likely to be beneficial, even if it comes at the cost of lowering patent holders incentives to participate in SSOs. Froeb and Ganglmair (2009) show that contractual agreements are preferred to antitrust policy as a way to mitigate the hold up problem.

Among the recommended policies to avoid hold up, some authors have advocated for limiting the licensing payments that patent holders may receive when their patents join an SSO (see Dolmans et al. (2007) or Farrell et al. (2007)). Some authors have proposed that innovators should receive ex post the same license that they would have been able to negotiate ex ante when other technologies were available (Swanson and Baumol, 2005). In that case, a technology would command a premium equal to the *incremental value* that it provides to the standard vis-a-vis the next best alternative.

As our selective tour through the theoretical literature on standard setting makes clear, many studies start from the assumption that a firm will participate in an SSO. When the participation aspect is considered at all, it has typically been in the context of which standard setting mechanism to employ, cooperative or non-cooperative.⁴ But even in these studies, the emphasis has generally been on the socially optimal form

⁴Alternatively, 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.

of determining a standard, not on any given firm's private decision making process. Empirical work, however, emphasizes that participation is an important firm decision. 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 IP strategy that can undermine the openness of a standard.

In the model we present next, we expand on the standard setting literature by modeling a firm's participation decision. As noted above, we consider how the IP licensing rules imposed by an SSO (or mandated to all SSOs via policy) can be expected to affect an innovative firm's decision to invest in R&D and to join in a cooperative standard setting effort.

3 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 $v > 0$. 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. 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 , independent across inventions. This success probability depends on the R&D investment expended by the firm. In particular, achieving a probability of success ρ requires an expenditure

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

Alternatively, the two inventions can be replaced 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 $0 < s < \frac{1}{2}$. Hence, if the SSO relies on the default technology for both inventions, the probability of success of the standard becomes s^2 .

Finally, we 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 private profits $\pi > 0$. In order to focus on interior solutions for the firms' decisions we will normalize $\pi + v \leq 1$.

Throughout the paper we focus on 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.⁵ 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 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

⁵Our 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 quality of the product achieved, 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 $v \equiv v_H - v_L$ the results translate to that case.

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 inventor can extract the entire surplus created by the standard, since he controls the only available technology required to bring the standard to market.⁶

The timing of the game is as follows. Initially, the SSO establishes a payment scheme for the patent holders' inventions to be included in the standard (a license). Patent holders decide simultaneously whether to participate in the standard or not. If a patent holder does not participate, the SSO replaces the patented technology with the default one. Patent holders then choose their R&D investment, $C(\rho)$. After uncertainty regarding the success of both technologies is resolved, the patent holder receives the corresponding licensing payments if it has joined the SSO. If it has not joined, an ex post negotiation with the SSO might occur.

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 the 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 is rewarded by the license payment defined below:

$$L_1^{IV}(\rho_1) = \rho_2 \rho_1 v - p_2 s v = \rho_2 v (\rho_1 - s). \quad (1)$$

In other words, the inventor would be paid the additional expected value contributed to the standard by invention 1, compared to the next best alternative.

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

⁶In section 7.2 we explore how the results change for other allocations of bargaining power.

the default technology, invention 1 can be obtained either through the default technology or by new R&D. In the following section we discuss the case in which both patent holders may invest in new inventions.

4 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.

4.1 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. As a result, when the patent holder invents technology 1, while technology 2 is obtained only through the default technology, the optimal investment, denoted as ρ_1^{fb} , results from

$$\rho_1^{fb} = \arg \max_{\rho_1} \rho_1(sv + \pi) - C(\rho_1) - F,$$

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.

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

Depending on the values of the parameters, three possibilities can emerge as optimal when only one technology for each component can be chosen.⁷ If F is very low, the

⁷This condition is consistent with the typical practice of many SSOs where only one of the possible

default technology is more efficient than the patented one and the SSO should rely on both default technologies. If F takes an intermediate value, the patented technology is more efficient. Finally, if F is very high, developing the standard is not optimal in the first place, meaning that development of the second component should not be carried out. In that last case, the patented technology should be used in order to obtain the independent profits π . The next lemma characterizes the different thresholds.

Lemma 1. *The first best is characterized by the following decision:*

1. *If $F < \underline{F}$ the SSO should use both default technologies,*
2. *if $F \in [\underline{F}, \overline{F}]$ the patented technology is used 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 whereas component 2 should not be developed.*

The critical values correspond to

$$\begin{aligned}\underline{F} &= s^2v - \frac{(sv + \pi)^2}{2}, \\ \overline{F} &= \frac{s^2v^2}{2} + sv\pi,\end{aligned}$$

with $\underline{F} < \overline{F}$ under Assumption 1.

To make the analysis non-trivial, we will assume throughout this section that F lies in the intermediate region.

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

technologies is incorporated in the standard. Nevertheless, because the two technologies lead to success with independent probability, it is easy to see that if F is sufficiently low, it might be optimal to develop and incorporate both. We explore this possibility in section 7.1 and show that relaxing this assumption does not have remarkable implications for our results.

4.2 Equilibrium under the Incremental Value Rule

We now turn to the private solution resulting from the IV licensing scheme. As usual, we need to solve the game by backwards induction. Let us start with the case in which the patent holder does not 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. This 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 $\hat{\Pi}_1 = \frac{1}{2}(s(1-s)v + \pi)^2$. It is important to notice that the patent holder in this case underinvests in ρ_1 compared to the first best described above. 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.

We next turn to the case in which the patent holder does participate in the SSO, so that 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

$$L_1^{IV}(\rho_1) = s\rho_1v - s^2v = s(\rho_1 - s)v.$$

The patent holder will, thus, maximize

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

leading to $\rho_1^{IV} = sv + \pi$ and profits $\Pi_1^{IV} = \frac{1}{2}(sv + \pi)^2 - s^2v$. Compared to the case where the patent holder does not join the SSO, the incremental value rule leads to an efficient investment choice. This is one of the main properties of this licensing scheme. Thus, in spite of the lower licensing proceeds that the firm obtains when joining the SSO, the higher probability of being rewarded leads to more R&D investment as compared to not participating in the standard setting efforts.

Surplus for SSO members as a whole, W , when patent holder 1 joins the organization can be computed as

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

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. Notice that having patent holder 1 join will always be preferred by SSO members as compared to developing the default technology only, which would lead to lower profits $s^2v - 2F$.

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 shows that patent holder 1's profits from joining the SSO are lower than not joining, 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, firm 1 will not join the SSO.*

This result is the main insight of this paper. As in most environments, the incremental value rule appears to be an appropriate way to provide reasonable compensation to firms

that innovate contingent on their joining the SSO. However, the substitution 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 SSO surplus in this case becomes

$$\hat{W} = s(s + (1 - s)\hat{\rho}_1)v - s(1 - s)\hat{\rho}_1v - 2F = s^2v - 2F.$$

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. For this reason, 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.⁸

Notice, however, that 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 participation constraint for the patent holder, but low enough so that the SSO does not prefer the default technology. This transfer must 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 $L_1 = \rho_1sv + t$, with*

$$t \in \left[s^2v \left(1 - s - \pi + \frac{s^2v}{2} \right), \min\{F, s^2v - F\} \right],$$

implements the first best.

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

⁸Notice that the result is not due to the fact that $\hat{W} < 0$, since at least for values of F close to \underline{F} the SSO makes positive profits under the incremental value rule.

case, we show that new interesting insights appear in that situation. In a later section we discuss the general case.

5 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.

5.1 The First Best

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

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

The solution to this maximization leads to $\rho_1^{fb} = \rho_2^{fb} = \frac{\pi}{1-v}$. The total social welfare generated in this case corresponds to

$$S_2^{fb} = \frac{\pi^2}{(1-v)^2} > 0, \quad (2)$$

where the subindex indicates that both patented components are used.

In order to determine whether the first best should prescribe the development of both patented inventions or not we need to compare this option with the remaining alternatives. An important difference with the case where only one patented component existed is that it is always optimal to develop the standard since the previous option leads to $S_2^{fb} > 0$. Thus, we only need to compare this possibility with using both default technologies or only one. The next lemma analyzes the different possibilities.

Lemma 4. *In the first best, if $F < \underline{F}' \equiv \frac{s^2 v}{2} - \frac{\pi^2}{2(1-v)^2}$ it is optimal to use both default technologies. Otherwise, both patented technologies should be used.*

It turns out that under Assumption 1 it is never optimal that the default technology is used for one component and not the other. Notice that this result is due to the symmetry

between the two different innovations. If default technologies, for example, led to different probabilities of success for innovation 1 and 2 there could be cases where optimality would require that the patented technology for one innovation and the default one for the other were developed.

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

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

5.2 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.

5.2.1 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 competitor to firm i . As a result, the optimal investment choice results from

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

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

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

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

5.2.2 No firm joins the SSO

If no firm has joined 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 obtained with either the default or the patented technology. Second, the innovation has been achieved using both 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, obviously, gross profits for the SSO are 0. In the second situation, the use of both default technologies results in SSO surplus of v . The third case is similar to the situation with one patent holder, in which the SSO obtains 0 profits, since the non-participating patent holder that faces no competition extracts a license equal to v . In the final case we assume that each patent holder can only extract profits equal to $\frac{v}{2}$.⁹ Thus, the SSO obtains 0 profits here too.

To summarize 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 income v only when both of these default technologies are successful. In expected terms, the SSO will obtain profits of $s^2v - 2F$.

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

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

⁹This 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 .

which leads to a symmetric equilibrium in which

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

and expected profits for each patent holder become

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

5.2.3 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. 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 in this case on the success of firm 2 and the default technology for invention 1. From all the possibilities, patent holder 1 will obtain positive licensing profits only when its technology has been successful and its participation in the standard is essential. This occurs when innovation 2 has been successfully developed but the default technology for innovation 1 is not available. This scenario occurs with probability $\rho_2(1-s)\rho_1$ and, as a result, firm 1 can extract a payment v from the SSO. Thus, patent holder 1 solves

$$\max_{\rho_1} \rho_2(1-s)\rho_1v + \pi\rho_1 - C(\rho_1),$$

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

$$\hat{\rho}_1(\rho_2) = \rho_2(1-s)v + \pi, \quad (3)$$

$$\hat{\rho}_2(\rho_1) = (s + (1-s)\rho_1)v + \pi, \quad (4)$$

which are represented in Figure 1. Equilibrium probabilities of success can be obtained as

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

Regarding the reaction functions, it is interesting to see the effect that an increase in s (the default success rate) 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 priori ambiguous.

Finally, we compute profits for the SSO. The value v will be achieved 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 surplus. Thus, the SSO will accrue profits only when the default technology for invention one is successful and the patented one for technology 2 is also successful. In that case, profits become

$$\hat{W} = s\hat{\rho}_2v - L_2^{IV} - F = s^2v - (1-s)\hat{\rho}_1v(\hat{\rho}_2 - s) - F. \quad (5)$$

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.

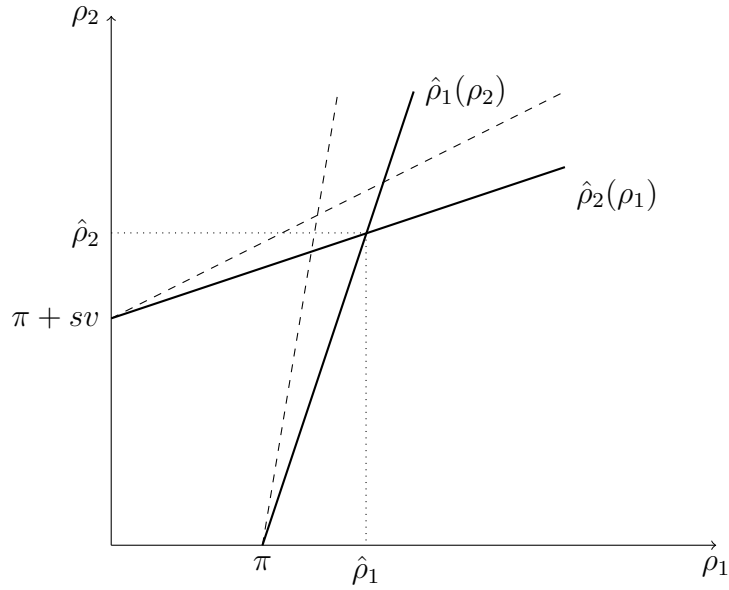


Figure 1: Reaction functions when only firm 2 joins the SSO. The dotted line represents the effect of an increase in s .

5.3 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 4, 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 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 with 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

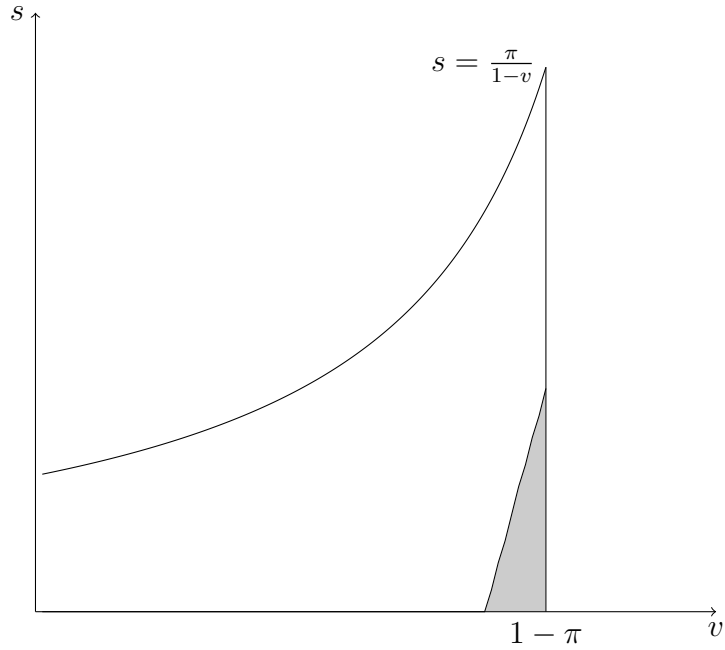


Figure 2: The decision to join the SSO for a value of $\pi = \frac{1}{4}$. The grey area corresponds to configurations of the parameters that lead to both firms joining the SSO.

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 change sign, and an equilibrium may exist where both firms join. As the next proposition shows, this is more 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 show that, in fact, 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 feasible configurations of parameters correspond to the area below the curve $s = \frac{\pi}{1-v}$ (satisfying Assumption 1) and to the left of $v = 1 - \pi$.

6 N Patent Holders

The previous section shows that the move from one patent holder to two leads to important 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 an 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 firms 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 $i = 2, \dots, N$, can be obtained from a generalization of (3) and (4), leading to

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

The Nash equilibrium of this game does not have an explicit solution, 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 example 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 increase

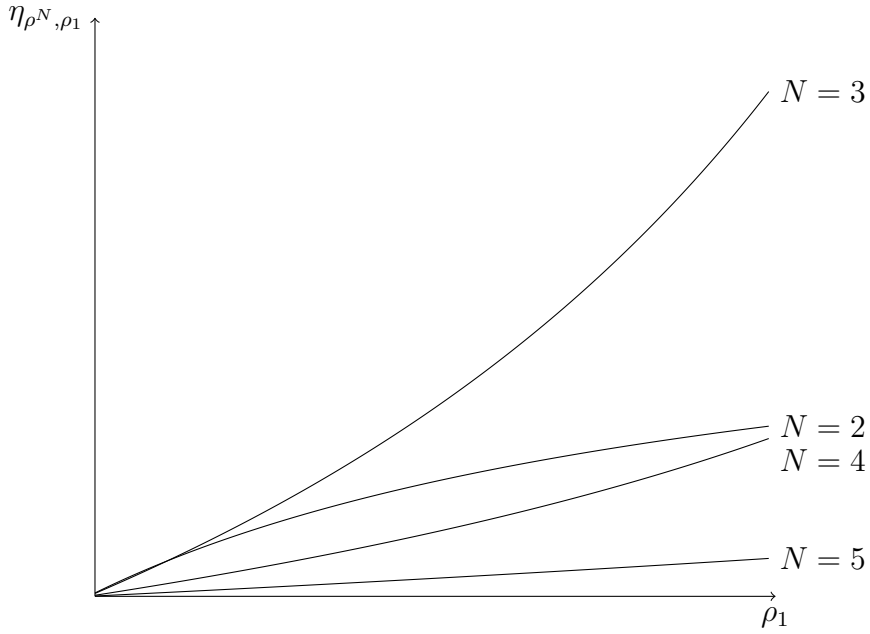


Figure 3: Elasticity of the total probability of success of other patent holders to a change in ρ_1 for various sizes of N . We have set $\pi = \frac{1}{4}$, $v = \frac{1}{2}$, $s = \frac{1}{4}$. We define the elasticity $\eta_{\rho^N, \rho_1} \equiv \frac{\partial}{\partial \rho_1} (\rho^{N-1}) \frac{\rho_1}{\rho^{N-1}}$

in ρ_1 is diluted affecting little the impact of each individual competitor, and resulting in a smaller aggregate effect.

These effects, however, fade away when N increases, and once the size of the SSO increases, a patent holder joining an SSO may expect to 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 case with one patent holder.

7 Robustness Analysis

In this section we discuss how much of the results of the paper would change if we relaxed some of the assumptions.

7.1 Substitute Technologies in the Standard

Most of the time SSOs choose one among different possible implementations of a given technology. Sometimes, however, SSOs may include two (or more) substitute technologies as part of a standard.¹⁰ In the previous model we ruled out this possibility by assuming that the SSO could only choose one technology for each component, which is in fact the goal of standard setting.

If we relax this assumption, a rationale for adopting several technologies arises when F sufficiently low. Given that we have assumed that the probability of success of the patented and the default technologies are independent, adopting both of them may increase the probability of success enough to compensate for the additional development cost.¹¹

We discuss this possibility in the context of only one patented technology. First, notice that contingent on both technologies being developed, the first best level of investment can be obtained from

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

which leads to a new first best $\rho_1^{fb} = s(1 - s)v + \pi$. Compared to the situation where only one technology is included in the standard, the first best here leads to a lower level of investment. This is due to the lower probability that the patented technology will become essential for the standard. The next lemma shows that this will be optimal only when the cost of uncovering the default technology is sufficiently low.

Lemma 6. *The first best will include both technologies in the standard if and only if*

¹⁰For example, two radio transmission technologies were chosen for the European 3G mobile standard UMTS/WCDMA.

¹¹In practice, adopting several flavors of the same technology might increase the complexity of the standard, since the rest of the components will have to be adapted to both of them. For simplicity we ignore this cost.

$F < \tilde{F}$, where

$$\tilde{F} = s^2v \left[1 + \frac{s^2v - 2sv - 2\pi}{2} \right] > \underline{F}.$$

The next result shows that in this situation the incremental value rule leads not only to an optimal level of investment but also makes the patent holder indifferent between participating in the standard or staying out. By construction, this rule makes the SSO indifferent between including only one technology in the standard or both of them, in spite of the fact that it is only efficient to have both technologies when F is low.

Proposition 7. *Suppose that for the same invention the default and the patented technology can be included in the standard. Under the incremental value rule, the SSO will be indifferent between accepting both technologies or not regardless of the value of F . If both are accepted, the patent holder will always participate and exert an effort level $\rho_1^* = s(1 - s)v + \pi$.*

The analysis presented here, therefore, provides a different way to interpret the main result of the paper. The incremental value rule will tend to generate inefficiencies when the inclusion of multiple technologies is possible, to the extent that $F > \tilde{F}$. In order to prevent patent holders from staying out and trying to extract ex-post rents, the SSO may tend to be excessively inclusive, resulting in additional costs.

7.2 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 $\hat{\Pi}_1 = \frac{1}{2}(s(1-s)\alpha v + \pi)^2$.

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

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

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 8. *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 result should hold for lower bargaining power to the extent that either π or v is sufficiently low. 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 do 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 $\pi = v = 0.4$.

8 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 such 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 will lead 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 need 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 simulations, 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 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 $\pi = 0$.

An important aspect that this paper assumes away is the distinction between different users of the standardized product. In practice, as the examples in the introduction make clear, some firms are mere technology contributors, others are final users 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 would thus become 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

Proof. Social welfare when the two default technologies are developed corresponds to

$$S_0 = s^2v - 2F. \quad (6)$$

When the default technology for component 2 is used and the patented one for component 1 social welfare becomes

$$S_1^{fb} = \frac{(sv + \pi)^2}{2} - F. \quad (7)$$

In both expressions, the subindex indicates the patented technologies used.

Finally, if only the patented technology for invention 1 is developed, social welfare becomes $\frac{\pi^2}{2}$. Comparing the three possibilities leads to the thresholds stated in the lemma.

It is easy to see that $\bar{F} > \underline{F}$ if

$$s^2v^2 + 2sv\pi + \frac{\pi^2}{2} - s^2v > 0.$$

This second order polinomial will be positive if

$$0 \leq s \leq \frac{\pi}{1-v} + \sqrt{\frac{4v^2\pi + 4v(1-v)\frac{\pi^2}{2}}{2v(1-v)}}$$

which is satisfied under Assumption 1. □

Proof of Proposition 2

Proof. By manipulating the expressions for profits when the patent holder joins the SSO, Π_1^V , as opposed to the case when the firm does not join it, $\hat{\Pi}_1$, it is easy to show that the latter will be larger if

$$s^2v + 2\pi < 2.$$

This will always hold, since $\pi + v < 1$ implies that

$$s^2v + 2\pi < s^2(1 - \pi) + 2\pi < 2.$$

□

Proof of Lemma 4

Proof. We first show that developing only one patented invention can never be optimal. For this to be the case, using (6), (7), and (2), we would require

$$\frac{(sv + \pi)^2}{2} - F \geq \max \left\{ s^2v - 2F, \frac{\pi^2}{(1-v)^2} \right\}.$$

For both constraints to hold at the same time, we must have that

$$\frac{(sv + \pi)^2}{2} - \frac{\pi^2}{(1-v)^2} \geq F \geq s^2v - \frac{(sv + \pi)^2}{2},$$

which is possible only if

$$(sv + \pi)^2 - \frac{\pi^2}{(1-v)^2} - s^2v \geq 0.$$

Notice, however, that this expression is increasing in s for $s \leq \frac{\pi}{1-v}$. Thus, it is enough to show that it cannot hold when $s = \frac{\pi}{1-v}$. Indeed, in this case, the expression becomes $-v \frac{\pi^2}{1-v} < 0$.

The comparison between the profits under the two options leads to the critical value \underline{F}' stated in the lemma. \square

Proof of Proposition 5

Proof. It is immediate that when $s = 0$ $\hat{\rho}_1 = \hat{\rho}_2 = \rho^{IV}$ and the probability of success and the ensuing profits are the same. In order to show the result it is enough 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 firm 1 joins the SSO.

Regarding the second,

$$\frac{\partial \Pi^{IV}}{\partial s} = -\frac{\pi v}{1-v}.$$

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

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

For our result it is enough to show that $\hat{\rho}_2 - (1-s) \frac{\partial \hat{\rho}_2}{\partial s} > 1$ around $s = 0$ for π sufficiently close to $1-v$. Notice that

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

which is increasing in π and it leads to

$$1 + \frac{v^2}{1 - v^2} > 1$$

when $\pi = 1 - v$, leading to the desired result. \square

Proof of Lemma 6

Proof. When only the patented technology is included to 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

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

The first option will lead to higher surplus if $F < \tilde{F}$ as defined in the lemma. Furthermore,

$$\tilde{F} - \underline{F} = \frac{(s(1 - s)v + \pi)^2}{2} > 0.$$

\square

Proof of Proposition 7

Proof. Given that for the default technology there is no effort decision, it is only relevant to think about the contribution that the patented technology has above that. In that case, it is easy to see that the ex-ante license that captures this contribution is

$$L_1^{IV}(\rho_1) = s(1 - s)\rho_1v$$

If the patent holder participates, it will choose a level of ρ_1 that results from

$$\rho_1^* = \arg \max L_1^{IV}(\rho_1) + \rho_1\pi - C(\rho_1).$$

which coincides with the socially optimal probability of success if it is efficient that both technologies are developed. Furthermore, this coincides with the probability that the patent holder would choose if it stays out of the SSO and the same profits will be accrued. As a result, the patent holder is indifferent between participating or not.

Profits for the members of the SSO in this case will be identical.

\square

Proof of Proposition 8

The threshold value of α can be obtained from

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

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 $(0, 2\frac{s-\pi}{s})$, $\alpha^* < 0$. 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 $\alpha \in [0, \bar{\alpha}]$ defined as

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

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