# Standard-Essential Patents*

Josh Lerner† Jean Tirole‡

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**Abstract**

A major policy issue in standard setting is that patents that are ex-ante not that important may, by being included into a standard, become standard-essential patents (SEPs). In an attempt to curb the monopoly power that they create, most standard-setting organizations require the owners of patents covered by the standard to make a loose commitment to grant licenses on reasonable terms. Such commitments unsurprisingly are conducive to litigation. This paper builds a framework for the analysis of SEPs, identifies several types of inefficiencies attached to the lack of price commitment, and shows how structured price commitments restore competition and why such commitments may not arise spontaneously in the marketplace.

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†Harvard University, jlerner@hbs.edu

‡Toulouse School of Economics and IAST, jean.tirole@tse-fr.eu

# 1 Introduction

Standards play a key role in many industries, including those critical for future growth. Intellectual property (IP) owners vie to have their technologies incorporated into standards, so as to collect royalty revenues. One illustration of the enormous stakes in standards has been the on-going disputes over smartphone patents. Litigation across at least 10 countries enveloped these devices, with at least 50 lawsuits between Apple and Samsung and – until their May 2014 settlement agreement – 20 cases between Apple and Google (not counting the on-going lawsuits between Google and the Rockstar Consortium, of which Apple is a partner). Many of the critical assertions in these disputes relate to the commitments that firms have made to standard-setting bodies during the standard setting process.

Standard setting organizations (SSOs) perform three functions. The discovery function consists of learning about, and certifying the value of, various combinations of functionalities. The standardization function then steers market expectations toward a particular technology; the SSO usually selects one of several options. Patents that are ex-ante dispensable to the extent that technology variants that do not rely on them were competing with the selected one, may thereby become ex-post, "standard-essential patents".[1]

Finally, most SSOs require the owners of patents covered by the standard to grant licenses on fair, reasonable and non-discriminatory (FRAND) terms. Needless to say, such loose price commitments have been conducive to litigation. Both the antitrust practice and the legal literature[2] emphasize that "fair and reasonable"[3] must reflect the outcome

[1]Indirect evidence about essentialization is provided by Rysman-Simcoe (2008)'s study of citations of patents that are disclosed to SSOs. They find that SSOs both identify promising solutions and play an important role in promoting their adoption and diffusion.

[2]E.g. Lemley-Shapiro (2013), Schmalensee (2009) and Swanson-Baumol (2005).

[3]This paper does not address the non-discrimination clause of FRAND. See, e.g., Gilbert (2011) for a focus on this covenant.

of ex-ante technology competition, not of the manufactured ex-post monopoly situation.[4] But it is difficult, if not impossible, for a court to determine ex post how valuable a given patent would have been in the ex-ante world in which the standard was formed.

Despite their prominence in business and antitrust economics, the standardization and regulation functions have received scant theoretical attention. This paper builds a framework in which they can be analysed, provides a precise identification of the inefficiencies attached to the lack of price commitment, and most importantly shows that a price commitment made prior to standard selection can restore ex-ante competition and efficiency. The article further shows that price commitments are unlikely to emerge in the absence of regulation.

The paper is organized as follows. Section 2 develops the framework. There are two groups of agents: IP holders and implementers/users. To reflect the fact that standards specify functionalities rather than patents, we posit that users choose a subset of functionalities within a set of potential functionalities. The technology's value to users is determined by the set of selected functionalities. One or several patents read on (i.e., implement) each functionality. Users are heterogeneous with respect to their opportunity cost of implementing the technology.

After developing the framework, Section 2 solves for the competitive benchmark assuming a "putty environment", in which an individual user's choice among functionalities is perfectly malleable in that it is not constrained by the need to match the other users'

[4] As Judge Posner recognized in Apple vs. Motorola, it is fallacious to take an ex-post perspective: "The proper method of computing a FRAND royalty starts with what the cost to the licensee would have been of obtaining, just before the patented invention was declared essential to compliance with the industry standard, a license for the function performed by the patent. That cost would be a measure of the value of the patent. But once a patent becomes essential to a standard, the patentee's bargaining power surges because a prospective licensee has no alternative to licensing the patent; he is at the patentee's mercy." (Apple, Inc. and Next Software Inc., v. Motorola, Inc. and Motorola Mobility, Inc., June 22, 2012, Case No. 1:11-cv-08540, page 18).

technological choice. The section shows that, when pools allow their members to sell licenses independently, welfare-increasing patent pools are stable while welfare-decreasing patent pools are unstable in the sense that independent licensing restores competition.

The rest of the paper is devoted to the study of the "putty-clay" version of the same environment. In that version, inter-operability requires coordination among users on a standard. While the choice of functionalities is perfectly flexible before the standard is set, it is no longer malleable ex post, and so individual users have to comply with the selected standard.

Section 3 first assumes that price discussions in standard setting are ruled out, as is currently almost universally the case; it further presumes that FRAND requirements have limited ability to regulate prices ex post. It demonstrates that if IP owners have their say, standards will tend to be under-inclusive. The intuition is that, as we noted, standards transform inessential patents into standard-essential ones. Most important patents' holders are not keen on creating additional technology gatekeepers, even if a patent pool can be later formed in order to avoid multiple marginalization.

Users' control of standard setting also creates problems. First, in the absence of ex-ante price discussions, a monopoly price for the technology often obtains ex post, even if decent alternatives were available ex ante. Second, users select an inefficient technology. Intuitively, users prefer to include functionalities on which several competing patents or an open source solution read rather than more essential, but monopolized ones that will command high ex-post prices.

Section 3 also highlights another issue: that SSOs can put pressure on the owners of patents by threatening not to incorporate the corresponding technology into the standard unless they commit to a low licensing price. The temptation to engage in this behavior can even affect SSOs that generally favor IP owners over users.

Section 4 studies whether structured price commitments can undo the inefficiencies unveiled in Section 3. We propose that, as is currently the case, the SSO not be entitled to discuss and negotiate royalty rates with IP owners; rather, after a discovery phase, IP holders non-cooperately announce price caps on their offerings, were their IP to be included into the standard. The SSO then selects the standard considering the price caps to which IP owners are committed.

The relationship between the outcome under this structured price commitment process and the ex-ante competitive benchmark is a priori far from trivial. A patent holder may use his price cap to influence other patent holders' prices or to pursue rent-seeking: jockeying (inducing the SSO to abandon other functionalities so as to avoid having to share royalties with the owners of patents reading on these functionalities) or achieving a stronger bargaining stance at the pool-formation stage. Nonetheless, we show that structured price commitments achieve the ex-ante competitive benchmark.

Section 4 then shows that one should not expect structured price commitments to be successful in the marketplace, except in specific circumstances. The ability to engage in forum shopping enables IP owners to shun SSOs that force them to charge competitive prices. This suggests imposing mandatory structured price commitments on SSOs.

Section 5 concludes with a discussion of avenues for future research. Omitted proofs can be found in the Appendix.

The paper is related to several strands of the literature. The first is the large legal literature on standard essential patents that grew out of international litigation regarding the behavior of Rambus and Qualcomm. Of particular relevance for this paper, Qualcomm's rivals accused it of setting unreasonably high royalty rates for technology covered by a FRAND commitment. These disputes—as well as subsequent disputes over smartphone technology—spawned a large literature. Notable among these works are analyses of the legal issues at work (e.g., Lemley 2002 and Skitol 2005 among many others), proposals to relieve the flow of litigation on these ideas (e.g., Lemley and Shapiro (2013)'s suggestion to require owners of standard-essential patents to enter into binding "final offer" arbitration with any potential licensee to determine the royalty rate; see also Lemley 2007); and careful case studies of the emergence of particular standards (e.g., Nagaoka et al. 2009).

A second related literature is on patent pools, which face similar information problems in determining which patents are essential. Lerner and Tirole (2004) highlight how in the absence of collusion, independent licensing – i.e., the ability for IP holders to market their patents independently of the pool – will restore competition in the case of detrimental (price increasing) pools, while not hindering the operations of beneficial ones. Boutin (2014) addresses the issue of equilibrium multiplicity in large patent pools and shows how detrimental pools can be stymied for sure by adding to the independent licensing requirement an unbundling one – a stipulation that the pool markets individual pieces of intellectual property at a total price not exceeding the bundle price. Rey and Tirole (2013) highlight how even in the presence of tacit collusion among pool participants, the unbundling requirement, again combined with independent licensing, makes accepting pools always Pareto optimal. Further analysis is needed to understand patent pools in the context of standard setting.

This paper takes a Coasian view that gains from trade among IP holders are realized and so efficient pools form when they increase profit. Brenner (2009) and Llanes-Poblete (2012) analyze the welfare implications of incomplete pools or explain how such incomplete pools may emerge from an equal-sharing constraint. Quint (2012) studies the welfare impact of various types of incomplete pools in a multi-product environment in which patents are all essential for the production of either one or several products.

Under-inclusiveness under IP holders design is reminiscent of the literature on labor-managed firms (see e.g. Ward 1958, Guesnerie and Laffont 1984 and Levin and Tadelis 2005). Indeed, the outcome shares with that literature the a-priori counterintuitive comparative statics of under-inclusiveness; Guesnerie and Laffont (1984) showed that, under reasonable assumptions, an increase in the demand for the product makes the labor-managed firm accept a lower number of employees.

A final body of related literature is the growing body of work on strategic behavior in standard setting more generally. Examples include work on the choice of firms to join standardization bodies (e.g., Axelrod et al. 1995), the ground rules adopted by these organizations, particularly in regard to the extent to which it is oriented to technology developers or end users (Chiao et al. 2007), and the composition of standard-setting working groups (Simcoe 2011).

# 2 Framework and the competitive benchmark

## 2.1 Framework

While the SSO has full flexibility in selecting a functional specification, implementers must take the standard as given once it has been set. Thus, the technology is putty-clay: fully malleable before the standard is set and rigid afterwards. The simplest interpretation is that strong network externalities prevent implementers from proposing alternatives.[5]

*Demand.* We distinguish between functionalities, $i \in I = \{1, \cdots, n\}$, and the patents reading on these functionalities. A standard is a choice of a subset $S \subseteq I$ of *functionalities*, yielding value $V(S)$ to the users (with $V(\emptyset) = 0$: users derive no surplus in the absence of any functionality). Users are heterogenous with respect to their opportunity cost $\theta$ of

[5] Alternatively, the end-users are informed only of the value brought about by the standard, are ignorant and distrustful of other combinations of functionalities, and furthermore cannot rely on reputable implementers to propose trustworthy alternatives.

implementing the technology; the user does not incur $\theta$ if he adopts no technology or a rival technology. A user with cost $\theta$ is thus willing to adopt technology $S$ if and only if $V(S) \geq \theta + P(S)$, where $P(S)$ is the total price to be paid to acquire the various licenses needed to implement technology $S$. The parameter $\theta$ is distributed on $\mathbb{R}^+$ according to density $f(\theta)$ and c.d.f. $F(\theta)$. The demand for the technology is

$$D(P(S) - V(S)) \equiv \text{ Pr } (\theta + P(S) \leq V(S)) = F(V(S) - P(S)).$$

We will sometimes focus on the *net* price of technology $S$

$$\tilde{P}(S) \equiv P(S) - V(S),$$

which determines the number of users, rather than on the price itself. We assume that $F$ is twice continuously differentiable and has a strictly decreasing reverse hazard rate $((f/F)' < 0)$; this assumption guarantees the log-concavity of profit functions as well as standard properties of reaction curves.

We do not assume that adding functionalities necessarily increases value to users (that is, that $V(T) \geq V(S)$ if $S \subset T$); for, a bulkier standard may imply a higher cost of putting the technology together and ensuring the absence of compatibility issues. Standard $T$ is said to be *overinclusive* if there exists a simpler standard $S \subset T$ such that $V(S) > V(T)$. For expositional simplicity, we will assume throughout the paper that the efficient technology $S^*$ is unique:

$$S^* = \arg\max_S \{V(S)\}.$$

A standard $S \subset S^*$ will be said to be *underinclusive.*

*Intellectual property and within-functionality competition index.* The extent of competition to enable a functionality $i$ is indexed by a maximum markup $m_i \geq 0$ (independent of $S$) that can be levied by intellectual property owners. For example, if the best implementation of the functionality is in the public domain or available under an open source license, $m_i = 0$. If instead this optimal implementation is covered by a valid intellectual property right held by a "dominant IP owner", while alternative implementations, whether in the public domain or in the hands of competing IP owners, imply an extra cost of implementation equal to $m_i$, then the markup charged by the dominant IP owner on functionality $i$ can be as large as $m_i$.[6] The case $m_i \geq V(S)$ corresponds to a patent that "commercially essential", i.e., is absolutely essential to implementing functionality $i$ included in standard $S$. For simplicity, we assume that each IP owner owns at most one dominant patent.

Finally, note that there is no real distinction between within-functionality and across-functionality substitution as long as the technology is fully malleable.[7] The distinction by contrast matters in the putty-clay environment of standard setting, in which within-functionality substitution is not affected by the standard, but across-functionality substitution opportunities disappear once the standard is set.[8]

[6] The case of differentiated patents (as in, e.g., Layne-Farrar and Llobet 2012) can be accommodated as well at the expense of further complexity. For example, in the absence of price commitment, the SSO will or will not include functionality $i$ depending on the impact of the inclusion of $i$ on the gross surplus of the average user and expected ex-post price $m_i$ (assuming that $m_i$ is not too large so that a patent holder would not want to reduce price below $m_i$ to boost demand for the overall technology).

[7] Consider within-functionality substitution and assume that, as discussed above, to deliver functionality $i$, patent $i$ offers a cost-saving-equivalent benefit $m_i$ over an alternative patent $i'$. Equivalently, one can assume that there is no scope for substitution within functionality $i$ and add a new functionality $i'$ (also without scope for substitution). Let, for all subset $S$ not containing $i$ and $i'$,

$$V(S \cup \{i\} \cup \{i'\}) = V(S \cup \{i\}) \text{ and } V(S \cup \{i'\}) = V(S \cup \{i\}) - m_i.$$

[8] For instance, between 2000 and 2003, the IEEE worked on developing the WiFi 802.11g standard. The 802.11g standard process was an extended political battle, primarily between Intersil and Texas Instruments. Each had a competing technology that it wanted incorporated into the 11g standard, abbreviated OFDM and PBCC respectively, corresponding to the notion of cross-functionality substitution ($e_i$) in the model. Each represented a substantial step forward from the Complementary Code Keying technology used in the earlier 802.11b standard ($m_i$). Because the approach of the two new proposed technologies was so different, it was very difficult to find common ground, exemplifying the idea that $S^*$

*Remark*: This framework extends that of Lerner-Tirole (2004) in three ways, with the latter two inspired by the specificities of the standardization activity. First, it considers a general value function $V(S)$ for the set of functionalities instead of the more specific $V(S) = \phi(\Sigma_{i \in S} v_i)$. Second, it distinguishes between functionalities and patents; as we noted, this distinction is descriptive to the extent that standards specify functionalities rather than specific patents. Third, it distinguishes between ex-ante (pre-standard) and ex-post (post-standard) essentiality.

## 2.2 Competitive benchmark: the putty environment

Consider the putty environment in which there is no standard, just a set of functionalities selected in a competitive equilibrium by users unconstrained by the need to inter-operate with each other. The dominant IP owner in functionality $i$ sets price $p_i \leq m_i$. The total price of bundle $S$ is then:

$$P(S) \equiv \Sigma_{i \in S} \, p_i.$$

The competitive benchmark is the putty-environment Nash equilibrium, where each patent holder selects a licensing fee for access to his patent, subject to three constraints: (i) users can achieve the same functionality supported by the patent via other (more costly) approaches that do not infringe the patent; (ii) users can drop the functionality supported by the patent and obtain (somewhat less) value instead from other functionalities that do not infringe the patent; and (iii) some users will not purchase the final product at the higher prices resulting from higher royalties.

We further impose that the prices of functionalities which are not in equilibrium selected by users be $p_i = 0$; this requirement is meant to avoid coordination failure equilibria,

may not include all functionalities (De Lacey, et al. 2006).

in which the owners of two perfectly complementary patents that otherwise should be selected by users each set very large prices, anticipating that the owner of the other patent will do so and so the pair will not be selected.[9] We now define competitive prices:[10]

**Definition 1** ***(competitive equilibrium)*** *A competitive equilibrium is a set of prices* $\{p_i\}_{i=1,\cdots,n}$ *and the users' choice of a consumption basket* $\mathcal{T}$ *such that:*

*(a) users maximize their utility over the consumption basket:*

$$V(\mathcal{T}) - P(\mathcal{T}) = \max_S \{V(S) - P(S)\}$$

*(b) IP holders maximize their profit given the possibility of within- and across-functionality substitution and the concern that some users do not purchase the technology: for all* $i$*,*

$$p_i = \min\{m_i, e_i, \widehat{p}_i\}, \tag{1}$$

*where*

$$e_i \equiv V(\mathcal{T}) - P(\mathcal{T}\backslash\{i\}) - \max_{\{S|i\notin S\}} \{V(S) - P(S)\}, \tag{2}$$

*and*

$$\widehat{p}_i \equiv \arg\max_{\{p_i\}} \{p_i D(p_i + P(\mathcal{T}\backslash\{i\}) - V(\mathcal{T}))\}. \tag{3}$$

When within-functionality substitution is strong ($m_i$ is low): $p_i = m_i$. Provided that the within-functionality competitive constraint is not binding ($p_i < m_i$), $i$'s competitive

[9] Another way of motivating this Bertrand-like assumption is to follow Boutin (2014) and assume that, for each patent, some users have an arbitrarily small value for the patent, and so the holders of patents that are excluded from the bundle prefer selling at this low price to stand-alone users.

[10] In the following, we adopt the convention that $S\backslash\{i\} = S$ if $i \notin S$.

price can take one of two forms.[11]

First, if the dominant IP owner on functionality $i \in \mathcal{T}$ raises his price $p_i$, functionality $i$ may be dropped from the users' "consumption basket"; for $i \in \mathcal{T}$, condition (2) can be rewritten as:

$$V(\mathcal{T}) - P(\mathcal{T}) = \max_{\{S|i \notin S\}} \{V(S) - P(S)\}. \tag{2'}$$

Condition (2), which defines a unique vector $\{e_i\}$ for each vector of prices $\{p_i\}$, also implies that for $i \notin \mathcal{T}$, $e_i = 0$ (take $S = \mathcal{T}$ in the condition) and so $p_i = 0$ as required. We will discuss shortly whether the parameter $e_i$ measuring the essentiality of the functionality is *uniquely defined* (the same regardless of the price vector) or depends on the prices charged by other IP owners (in which case the notation $\{e_i\}$ should be understood to be relative to the price vector under consideration).

Second, the IP owner may refrain from raising his price not because this would lead to an exclusion from the users' selected bundle, but because this negatively impacts demand:[12]

$$p_i = \arg\max \ \{p_i D(p_i + P(\mathcal{T} \backslash \{i\}) - V(\mathcal{T}))\}.$$

[11] In the terminology of Lerner-Tirole (2004), pricing according to (3) corresponds to the "demand margin". Unlike in that paper, though, there are two, not one, "competition margins", as we have added the within-functionality-substitution constraint that $p_i \leq m_i$ to the cross-functionality-substitution constraint (2).

[12] Note that condition (3) posits that users keep buying $\mathcal{T}$ when firm $i$ changes its price. To show that this is justified, note first that firm $i$ will not set a price $p_i'$ such that

$$V(\mathcal{T}) - P'(\mathcal{T}) < V(S) - P(S)$$

for some $S$ such that $i \notin S$, where $P'(\mathcal{T}) \equiv P(\mathcal{T}) + p_i' - p_i$. Otherwise firm $i$ would be ejected from the users' basket. But could firm $i$'s deviation in this range lead to the exclusion of (at least) some firm $j$ from the users' basket? Suppose therefore that

$$V(\mathcal{T}) - P'(\mathcal{T}) < V(S') - P'(S')$$

where $j \notin S'$, $i \in S'$ and $P'(S') \equiv P(S') + p_i' - p_i$. This however is inconsistent with $P'(\mathcal{T}) - P(\mathcal{T}) = P'(S') - P(S')$ and condition (2') for firm $j$.

We now characterize competitive equilibria.

**Proposition 1** ***(characterization of the competitive equilibrium)***

*(i) A competitive equilibrium involves efficient design:* $\mathcal{T} = S^*$.

*(ii) A competitive equilibrium exists.*

*(iii) Two unconstrained competitive prices must be equal: If* $p_i = \widehat{p}_i$ *and* $p_j = \widehat{p}_j$ *, then* $p_i = p_j$.

*(iv) Consider the symmetric case in which all functionalities are interchangeable:* $V(S)$ *depends only on the number of selected functionalities and* $m_i = m$ *for all* $i$. *Denoting by* $k^*$ *the number of functionalities in* $S^*$, *let* $e$ *be uniquely defined by* $e = 0$ *if* $k^* < n$ *and* $V(S^*) - ne = \max_{k<n} \{V(S_k) - ke\}$ *if* $k^* = n$, *where* $S_k$ *the set of the first* $k$ *patents, or for that matter any subset of* $k$ *patents (due to the symmetry). Let* $\widehat{p}$ *be defined by* $\widehat{p} = \arg\max \{pD((n-1)\widehat{p} + p - V(S^*))\}$. *There exists a unique symmetric competitive price, equal to min* $\{m, e, \widehat{p}\}$.

## 2.3 Is the competitive equilibrium unique?

The competitive equilibrium need not be unique. Examples of multiple equilibria are provided in the Appendix. First, the individual prices of complementary patents may not be uniquely defined, as in the classic Nash demand game (1950). Second, and more importantly, the total price may not be unique. Thus, one must in general consider the Nash equilibrium set rather than a singleton. Two possible approaches can be taken in case of multiplicity. First, it would be interesting to introduce uncertainty about the value function as in Nash (1950) to select among equilibria.[13] We leave this for future research.

[13] Namely there could be some small uncertainty in the value function ($V(S) + \varepsilon_s$) and one could let the noises converge to 0.

Second, one can operate an arbitrary selection in the equilibrium set (for example, select the symmetric equilibrium in the symmetric case in case there exist also asymmetric ones). For simplicity, we will adopt the latter approach. We make an equilibrium selection if the competitive price vector is not unique and index by a superscript "$c$" the resulting vector of competitive prices.

Equilibrium uniqueness turns out to be closely related to the question of whether the essentiality parameters $e_i$ are uniquely defined or depend on the prices charged by the other IP holders.[14] For future convenience (we will apply Proposition 2 to other contexts), it is useful to regroup constraints (1) and (2) into a single price cap $\tilde{e}_i = \min\{m_i\ ,\ e_i\}$, which is uniquely defined if $e_i$ is. Later on, we will apply the result to the post-standard-setting pricing of individual licenses, in which cross-functionality substitution is no longer an option, but IP holder $i$'s price is constrained by an unbundled pool price $p_i^P$ ($\widetilde{e}_i = \min\{m_i\ ,\ p_i^P\}$) or by an ex-ante price commitment $\bar{p}_i$ ($\widetilde{e}_i = \min\{m_i\ ,\ \bar{p}_i\}$).[15]

**Proposition 2** ***(unique equilibrium and comparative statics)***. *Suppose that for all $i$, firm $i$ must select its price $p_i$ subject to the constraint $p_i \leq \widetilde{e}_i$ for some arbitrary, price-independent $\widetilde{e}_i$. That is, $p_i \equiv \min\{\tilde{e}_i\ ,\ \hat{p}_i\}$ where $\hat{p}_i$ is given by (3) (for $\mathcal{T} = S^*$). Then*

*(i) there is a unique such vector $\{p_i\}$ (and so, as a corollary, there a unique competitive equilibrium in the putty environment if the $\{e_i\}$ are unique);*

*(ii) suppose $\widetilde{e}_i' \leq \widetilde{e}_i$ for all $i$; then letting $P^c(S^*)$ denote the total price of bundle $S^*$ under parameters $\{\widetilde{e}_i\}$ (and $P^{c\prime}(S^*)$ under parameters $\{\widetilde{e}_i'\}$), $P^{c\prime}(S^*) \leq P^c(S^*)$;*

*(iii) suppose that $S^* = \{1, \cdots, n\}$ and the surplus function exhibits decreasing incre-*

[14] In general, condition (2) uniquely defines a function $e_i(\{p_j\}_{j \neq i})$. We say that the $e_i$ are uniquely defined if they are invariant to the other prices.

[15] For clarity, we state the proposition for the putty environment. The other applications just mentioned refer to pricing after a standard has been set. Then as explained, in Section 3.1, if $S$ is the selected standard, $V(S^*)$ must be replaced by $V(S)$ in (3) and attention can be confined to prices in $S \subseteq I$. Up to this relabeling, the proposition holds.

*mental contributions: For any disjoint subsets $S_1$, $S_2$, $S_3$ (with $S_2$ and $S_3$ non empty), $V(S_1 \cup S_2 \cup S_3) + V(S_1) < V(S_1 \cup S_2) + V(S_1 \cup S_3)$.*[16] *Then the essentiality parameters are uniquely defined: for all $i$, $e_i = V(S^*) - V(S^* \backslash \{i\})$. The competitive price vector is therefore unique.*

## 2.4 Multiple marginalizations and pool formation

Let $P^m(S)$ denote the monopoly price[17] for an arbitrary technology $S$:

$$P^m(S) \equiv \arg\max_P \{PD(P - V(S))\}.$$

We will repeatedly use the property that $S^*$ minimizes $P^m(S) - V(S)$.[18]

Note next that if there exists $i$ such that $p_i^c$ is determined by (3), then $P^c(S^*) \geq P^m(S^*)$.[19] But even if no individual competitive price is determined by (3), the technology's price $P^c(S^*)$ may still exceed the monopoly price.[20]

We are thus led to consider two cases, depending on whether the competitive price

[16] A special case of concave surplus is the technology $\phi(\Sigma_{i \in S} v_i)$ considered in Lerner-Tirole (2004), provided that $\phi'' < 0$. If $n = 2$ and $S^* = \{1, 2\}$, then

$$e_i = V(S^*) - P(S^* \backslash \{i\}) - \max_{\{S | i \notin S\}} \{V(S) - P(S)\}$$

can be computed without references to prices charged by patent holder $j$: $V(S^*) - P(S^*) = V(\{j\}) - p_j$ yields $e_i = V(S^*) - V(S^* \backslash \{i\})$. If furthermore $V(S^*) > e_1 + e_2$ , then the decreasing incremental contributions condition is satisfied: Take $S_1 = \emptyset$ , $S_2 = \{1\}$ , $S_3 = \{2\}$.

[17] It is unique from the log-concavity of $F$.

[18] The net monopoly price $\tilde{P}^m(S)$ for technology $S$ solves max $[\tilde{P} + V(S)]D(\tilde{P})$, whose maximand exhibits decreasing differences in $V(S)$ and $\tilde{P}$.

[19] Again by a revealed preference argument: From condition (3), the total price maximizes

$$[P - P^c(S^* \backslash \{i\})]D(P - V(S^*))$$

and so $P^c(S^*) \geq P^m(S^*)$, with strict inequality if $P^c(S^* \backslash \{i\}) > 0$.

[20] This property can be viewed as defining patent complementary. The patents need not be perfect complements as in Cournot's model in order to generate prices that exceed their monopoly level.

exceeds the monopoly level. When it does, the patent holders in $S^*$ would want to form a pool so as to offer their technology at the lower, monopoly price, thus maximizing industry profit (and incidentally increasing user welfare). The hazard with pools is of course that they can be set up so as to raise price to the monopoly level when the competitive price $P^c(S^*)$ is below that level. We will therefore require, as American, European or Japanese authorities do, that pool members keep ownership of their patents and thus be able to grant individual licenses; the pool is then only a joint marketing alliance. That is, after the pool has set its price, IP holders set prices $p_i^{IL}$ for their individual licenses; users then choose their preferred bundle (or none).

Suppose thus that patent holders can form a pool *before* choosing their prices. As we will later discuss, various potential commitment strategies imply that this *pool formation prior to individual price setting* need not be equivalent to the situation in which a pool is formed after out-of-pool price commitments have been made.

A "pool agreement" consists in a subset $S$ of patent holders agreeing to market the bundle of their patents at some bundle price $P$, to distribute the royalties stemming from licensing the bundle according to some sharing rule, and to allow pool members to grant individual licenses. We take a Coasian view of patent pool formation by assuming that gains from trade among IP owners[21] are realized and so a pool forms if it is profitable.

Proposition 3 below extends Proposition 9 in Lerner-Tirole (2004). It states that, up to a reasonable additional assumption ("consistency of equilibrium selection"), patent pools that allow individual licensing are always welfare increasing. To understand the need for the extra assumption, suppose that there are two symmetric competitive equilibria, one delivering a total price a bit above the monopoly price and another with a total price

[21] As usual, we assume that users cannot sign collective contracts with IP holders. User dispersion and privately known valuations clearly hinder such contracting.

substantially below; through a contingent equilibrium selection, the outcome with the high price and yet no pool formation can be sustained: it suffices to specify that in case of pool formation, the independent licensing game admits the low price outcome as its equilibrium (see the proof of Proposition 3 for a rigorous derivation).

Formally, let a pool with bundle $\mathcal{T}$ form, that markets $\mathcal{T}$ at pool price $P^P(\mathcal{T})$. An independent licensing equilibrium $\{p_i^{IL}\}$ of the continuation game starting when the pool has been formed is said to undo the pool ( $\mathcal{T}$ , $P^P(\mathcal{T})$) if

$$\min_{\{S\}}\{P^{IL}(S) - V(S)\} < P^P(\mathcal{T}) - V(\mathcal{T}).$$

It is easy to verify that $\{p_i^{IL}\}$ must then be a competitive equilibrium. The equilibrium selection is said to be *consistent* if the equilibrium that prevails in the absence of pool formation is also $\{p_i^{IL}\}$. The equilibrium selection is necessarily consistent if the competitive equilibrium is unique.

We will say that the pool practices unbundling if it offers patent licences on an unbundled basis and their individual prices $p_i^P$ are such that the cheapest option for acquiring licenses to functionalities in $S$ from the pool costs $\Sigma_{i\in S}\, p_i^P$, for all $S$. The effective price for license $i$ is then $p_i = \min\,\{p_i^{IL}, p_i^P\}$, where $p_i^{IL}$ is the independent license price. Royalties are *passed through* by the pool if IP holder $i$ receives a dividend from the pool equal to $p_i^P$ times the number of licences to patent $i$ granted by the pool.

**Proposition 3** ***(pools are welfare enhancing).***

*(i) Suppose that $P^c(S^*) > P^m(S^*)$, and consider a pool agreement that involves the owners of dominant patents reading on functionalities in $S^*$ and charges $P^m(S^*)$ for access to the bundle; there exists an equilibrium in which pool members do not actively grant indi-*

*vidual licenses; furthermore, welfare is unique and the pool forms if either the competitive outcome is unique or, if there are multiple competitive outcomes, the equilibrium selection is consistent.*

*(ii) Suppose that $P^c(S^*) < P^m(S^*)$. Then for any welfare-decreasing pool, that is any pool that delivers net value $V(S) - P(S) < V(S^*) - P^c(S^*)$, there exists an equilibrium in which IP holders sell individual licenses and the outcome is the competitive outcome.*

*(iii) Suppose that $P^c(S^*) < P^m(S^*)$. Suppose that the pool must practice unbundling and pass royalties from licenses through to their owners. Assume finally that the essentiality parameters $e_i$ are uniquely defined. The outcome is then always the competitive outcome.*[22]

We will henceforth make a weak *monotonicity-in-bargaining assumption*: Supposing that a pool with functionalities in some set $S$ forms, then patentholder $i$'s share of dividends from the pool is weakly increasing in $i$'s profit in the absence of pool formation, and weakly decreasing in other pool members' profits in the absence of a pool. This assumption is satisfied by the outcome of standard bargaining processes such as the Nash bargaining solution.

We conclude this study of the putty environment by noting that the competitive total price for the efficient bundle $S^*$ is the proper benchmark only when it lies below the monopoly price. When it exceeds the monopoly price, the IP holders will wish to form a pool. Assuming that authorities validate the pool (as they should), it is natural to modify the definition of the competitive benchmark as more generally what would happen in the

[22]Part (ii) only shows that when the pool aims at raising price, there exists an equilibrium in which independent licensing restores competition. With more than two patents, though, there may exist other equilibria in the independent licensing subgame. To avoid this and to ensure strong instability, appending an unbundling requirement ensures strong instability of welfare-decreasing pools in specific contexts. (Boutin 2014). We here provide a different, but related result for the case of uniquely defined essentiality.

putty environment when pools are feasible.

**Definition 2** ***(competitive benchmark)****. In the competitive benchmark, implementers use functionalities $S^*$ and pay $\mathcal{P}^c(S^*) \equiv \min\{P^c(S^*), P^m(S^*)\}$ for access to these functionalities.*

# 3 Hold-ups, inefficient design and reverse hold-ups

Let us turn to the putty-clay environment. The premise of this section and the next is that in the absence of facilitation by the SSO, individual price commitments are difficult (even infeasible in our stylized version). The practical reason for this is that at the start of the standard setting process there is substantial uncertainty as to which combinations of technology will work and how valuable these will turn out to be (that is, the function $V(.)$ is unknown); committed prices are then likely not to maximize profit. Section 3 accordingly assumes that price commitments are infeasible; in contrast Section 4 will have the SSO introduce after the discovery phase a recess period during which IP holders are able to draft price commitments.

We first assume in Sections 3.1 through 3.3 that prices are not discussed, committed to or negotiated prior to standard setting. In practice of course, participants in standard-setting processes usually commit to offer licenses on FRAND terms. This section thus opts for expositional simplicity and depicts a most pessimistic view of FRAND, in which the loose commitment does not constrain ex-post market power. Note, though, that even if FRAND succeeds in constraining somewhat ex-post market power, the effects described in this section will still be at play in a milder form. In Section 3.4, we allow price discussions within the standard setting process.

### 3.1 Post-standard prices without and with a pool

Suppose that there is no pool and that prices are set after the choice of an arbitrary standard $S$. Let $\{p_i^*\}_{i\in S}$ denote the equilibrium prices and $P^*(S)$ denote the total price of the bundle. At that stage, cross-functionality substitutability is no longer an option. By contrast, within-functionality substitutability is still feasible for the users. Thus, the holder of the dominant patent reading on functionality $i \in S$ sets $p_i$ ex post so as to maximize profit,[23] and so

$$\text{either} \quad p_i^* = m_i \tag{1'}$$

$$\text{or} \quad p_i^* = \arg\max_{p_i} \left\{ p_i D\left(\sum_{\substack{j\in S \\ j\neq i}} p_j^* + p_i - V(S)\right) \right\} \tag{3'}$$

We can apply Propositions 1 and 2 to characterize the putty-clay outcome. As we noted, the standard does two things. First, it makes the choice $S$ the only viable solution for users. This corresponds to modified value function

$$\widehat{V}(T) \begin{cases} = V(T) & \text{if } T = S \\ \leq V(S) & \text{if } S \subseteq T \\ = 0 & \text{otherwise.} \end{cases}$$

Second, it eliminates cross-functionality substitution:[24]

$$\hat{e}_i = V(S^*).$$

[23] If $i \notin S$, then $p_i$ is irrelevant.

[24] Given $\widehat{V}(\cdot)$, the equivalent of condition (2) for this modified environment is for $i \in S$

$$\hat{e}_i = V(S) - \sum_{\substack{j\in S \\ j\neq i}} p_j - [0].$$

If this constraint were binding, demand would be zero, which is clearly not an optimal strategy. So constraint (2) is not binding, and so one might as well take a large value for $\hat{e}_i$.

**Proposition 4** ***(ex-post pricing).*** *Consider an arbitrary standard S.*

*(i) Ex-post prices are unique: There exists a unique triple* $\{I_1(S), I_2(S), \widehat{p}(S)\}$ *such that* $I_1(S) \cup I_2(S) = S$ *and unique ex-post equilibrium prices* $p_i^*$*; they satisfy:*

*if* $i \in I_1(S)$ , $p_i^* = m_i \leq \widehat{p}(S)$;

*if* $i \in I_2(S)$ , $p_i^* = \widehat{p}(S) < m_i$ , *where*

$$\widehat{p}(S) = \arg\max_{p_i} \{p_i D(\sum_{j \in I_1(S)} m_j + [\#I_2(S) - 1]\widehat{p}(S) + p_i - V(S))\}.$$

*(ii) Standard-essential patents command a high net price: for all S,* $V(S^*) - \mathcal{P}^c(S^*) \geq V(S) - \mathcal{P}^*(S)$ *where* $\mathcal{P}^c(S^*) \equiv min\,\{P^c(S^*), P^m(S^*)\}$ *and* $\mathcal{P}^*(S) \equiv min\,\{P^*(S), P^m(S)\}$.

Proposition 4 offers a potential explanation for the puzzling fact that patents tend to be weighted equally in the sharing of royalties from pools. Observers (Layne-Farrar-Lerner 2011) have wondered about the fact that patents with unequal importance are rewarded equally, creating perverse incentives ex ante (choice of unambitious routes for innovation) and ex post (reluctance of the owners of important patents to enter a standard-setting process). But except for those patents that are constained by within-functionality substitution, all patents are equal once they have been made essential by the standard setter.

While we rule out ex-ante price commitments, we allow a pool to form ex post; once the standard has been set, patent holders can form a pool, with ex-post pricing as the threat point. The timing is summarized in Figure 1.

Because patent holders are still constrained by within-functionality substitution, but cross-functionality substitution is no longer feasible, a pool that does not admit multiple pieces of intellectual property covering the same functionality (as is usually prohibited by antitrust authorities) can only be formed to *lower* price:

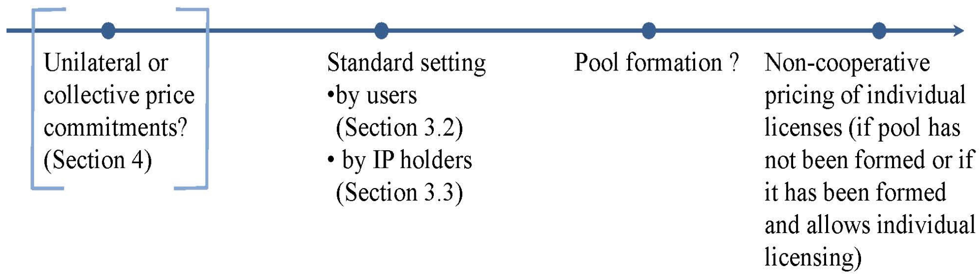


**Figure 1: Timing in the absence of price discussions**

**Proposition 5** ***(pools in the putty-clay framework)***

*Under the provision that a pool cannot include multiple patents reading on the same functionality, an ex-post pool can only reduce total price even if members cannot individually license their patents.*

We can compare the impact of a pool in the putty and putty-clay cases. In the putty technology case, a pool with independent licensing is always beneficial. It lowers total price when the latter exceeds the monopoly price; and independent licensing restores competition when the pool attempts to raise price (see Section 2). In the putty-clay case without price commitments, merger to monopoly through the elimination of cross-functionality competition is ex post no longer a hazard since the standard makes all selected functionalities essential anyway. Pool formation is again socially desirable, although independent licensing loses its power to restore the ex-ante competitive price level.

Allowing for the formation of a pool if the ex-post competitive price exceeds the monopoly price, the final price for an arbitrary standard $S$ is:

$$\mathcal{P}^*(S) \equiv \min\ \{\sum_{i\in S} \min\ \{m_i, \widehat{p}(S)\}, P^m(S)\} = \min\ \{\Sigma_{i\in S}\ m_i\ ,\ P^m(S)\} \tag{4}$$

*Remark*: Under current practice, IP owners collectively do not form patent pools so as to directly influence the design of standards. Out of 21 standard-pool pairs we informally reviewed for the purpose of this contribution, only 3 pools were formed prior to standard setting, and all 3 were closed (and royalty-free) pools. By contrast, the other, post-standard-setting pools were typical royalty-charging open pools.[25] One reason for the absence of individual and collective ex-ante price commitments is that at the start of the standardization process IP owners do not know which combinations of functionalities will work.

## 3.2 Standard designed by the users

Suppose, first, that the standard is set by the users. The latter have congruent interests and solve:

$$\max_{\{S\}} \{V(S) - \mathcal{P}^*(S)\}. \tag{5}$$

Will users choose the efficient technology $S^*$ maximizing $V(\cdot)$, given that they have an eye on the price the technology will command ex post? Standard design by the users

[25] Forming a pool involves transaction costs and therefore is more costly if performed before the standard is set. There may be uncertainty as to what the SSO will choose; or there may be missing essential patents that could hold up the pool ex post, and so delaying the formation of the pool increases the probability of detecting such patents. This point was emphasized repeatedly in interviews we conducted with executives who ran licensing organizations or participated in multiple standardization and patent pool efforts. They emphasized that the scope of intellectual property to be included in the pool is not known ex ante, and consequently firms are unwilling to commit until they know what they are promising to license.

To cite one example, the MPEG Licensing Association has long struggled with this issue. When they have attempted to establish pools before the standard was finalized, such as was the case of the LTE patent pool, getting commitments was exceedingly difficult. Due to the extent of uncertainty, many firms did not want to choose their licensing policy until they acquired more information about how likely the standard would be to succeed and how central their patent would be to the standard. Many firms wanted to keep individual licensing option on the table with an eye to higher financial returns and a stronger bargaining position in potential cross-licensing discussions going forward. MPEG LA has tried to overcome this resistance by creating "product license pools" which encompass technologies covered by multiple standards, some of which may still be in progress. Even in these pools, however, there has still significant technological uncertainty, making the nature of the patent commitments difficult to predict ex ante (e.g., as additional features are added to the pool) and leading firms to be reluctant to participate.

See online appendices A. "Documentation of Empirical Analysis" and B. "Documentation of the Interview Process".

leads to two kinds of inefficiency. The first is, unsurprisingly, monopoly pricing. Ex-post price setting creates scope for opportunism by IP holders. Suppose for instance that the within-functionality-competition constraint is not binding (say, $m_i \geq V(S^*)$) and so functionalities de facto coincide with patents. For any selected standard $S$, multiple marginalizations in the absence of pool lead to a price in excess of the monopoly price for $S$; so (unless $S$ is composed of a single functionality) a pool forms to lower the price to its monopoly level. Users optimally select the efficient standard $S^*$, which delivers the lowest net price given that all standards generate a monopoly markup.[26]

Second, and more interestingly, when within-functionality substitution is feasible for at least some functionalities, users may well choose an inefficient design so as to curb ex-post market power. Recall that a functionality is characterized by two attributes: how essential the functionality is relative to the overall technology, and how intense is within-functionality competition. This second element may distort users' decisions in favor of high-competition functionalities, a new and hidden cost of the lack of ex-ante price commitment.

To characterize possible design biases, let us (for the sake of the next two propositions only) assume that functionalities can be *ranked by their importance*, with functionality 1 being the most essential, functionality 2 the second most essential, etc.: For a given standard $S$, we will let $\nu_k(S)$ denote the identity of the $k^{th}$-ranked functionality in the standard. By convention, $\nu_k(S) = \infty$ if standard $S$ has less than $k$ functionalities. For example if $S = \{1, 3, 4, 7\}$ then $\nu_3(S) = 4$ and $\nu_5(S) = \infty$. We say that functionalities

[26] Fix a standard $S$ with $k$ functionalities. Ex post, in the absence of a pool, non-coordinated IP owners charge collectively $\widehat{P}(S) > P^m(S)$ where

$$\widehat{P}(S) \equiv k\widehat{p} \text{ and } \widehat{p} = \arg\max \{pD((k-1)\widehat{p} + p - V(S))\};$$

and so a pool forms and charges $P^m(S)$ (independent licensing has lost all its power ex post: all patents have become essential). Thus users choose $S$ so as to solve $\max_{\{S\}} \{V(S) - P^m(S)\}$, and so select $S = S^*$.

$i = 1, \cdots, n$ are *ranked in decreasing order of essentiality* (or incremental value) if for any two non-overinclusive standards $S$ and $T$ satisfying $\nu_k(S) \leq \nu_k(T)$ for all $k$, $V(S) \geq V(T)$.

Essentiality ranking implies that without loss of generality the efficient standard $S^*$ can be chosen to be composed of the first $k^*$ functionalities.[27]

**Proposition 6** ***(inefficient design)***. *Suppose that functionalities are ranked according to their essentiality. User choice of the standard*

*(i) never results in overinclusive standards and may result in underinclusive ones ($S \subset S^*$);*

*(ii) results in standards biased toward high within-functionality competition relative to essentiality: If $i \leq k^* < j$ and $j$, but not $i$, belongs to $S$, then $m_j < m_i$.*

*(iii) delivers a suboptimal social welfare.*

Proposition 6 may help understand why IP holders sometimes complain that SSOs are "biased" toward open-source technologies (which de facto commit to $m_i = 0$).

## 3.3 Standard designed by IP owners

Consider now the polar case in which IP owners set the standard. This situation is in general more complex than the previous one because IP owners may not have congruent

[27] For example, in the case of a linear value function,

$$V(S) = \Sigma_{i=1}^n x_i e_i, \text{ where } \begin{cases} x_i \equiv 1 & \text{if } i \in S \\ x_i = 0 & \text{if } i \notin S, \end{cases}$$

with $e_1 \geq e_2 \geq \cdots \geq e_n$, $S^* = \{1, \cdots, k^*\}$ where $k^*$ is such that $e_{k^*} > 0 \geq e_{k^*+1}$.

Note that the ability to rank functionalities by their importance does not imply that the essentiality parameters are unique. Suppose that there are three useful functionalities $\{1, 2, 3\}$, that functionalities 2 and 3 are perfect complements, yielding $e_J$ (where "$J$" is for "joint"). Functionality 1 delivers $e_1 > e_J$. Total value is $V(S^*) = e_1 + e_J$. Then functionalities are ranked, while $e_2$ and $e_3$ are not defined independently of prices.

preferences. Let us analyze the following simple case, though: Suppose that functionalities and patents coincide (again, a sufficient condition for this is $m_i \geq V(S^*)$); and furthermore that functionalities are ranked in essentiality, with functionality 1 the most important and so on.

To analyze coalition formation, we define a *stability condition* similar to that in Levin-Tadelis (2005), who examine the effect of profit sharing on the selection of employees by a firm. We posit that the partners in a coalition should not want to dismiss any current partners or admit additional ones. Like in Levin-Tadelis, the stability condition implies that a stable coalition is characterized by a threshold (the most important patents are selected into the coalition), and this threshold achieves the maximum profit per partner.

Thus, consider the standard $\overline{S}$ made of the first $\overline{k}$ patents/functionalities, where

$$\overline{k} \equiv \max \left\{ k \mid k \in \arg\max_{\widetilde{k}} \max_{P} \left\{ \frac{PD(P - V(S_{\widetilde{k}}))}{\widetilde{k}} \right\} \right\}, \tag{6}$$

and

$$S_k = \{1, \cdots, k\}$$

is the standard composed of the first $k$ functionalities.

This standard $\overline{S}$ yields the highest per-patent profit, and so no other standard can bring more profit to all of its members. In this sense, the standard $\overline{S}$ is stable. It is in the interest of the $\overline{k}$ IP owners to form a coalition and find a complascent SSO that will select $\overline{S}$.[28]

[28] This complacent SSO could be a "SIG", i.e., a (largely captive) special interest group that IP owners can use to obtain favorable standards. On the other hand, SSOs often require a supermajority, which may be difficult for a small number $k$ of IP holders to secure. Furthermore, SIGs may have limited credibility vis-à-vis the users. Thus, it would be worth studying the case of a dominant SSO that is less complacent with IP holders.

Finally, while we maintain the assumption of absence of agreement before standard setting (and therefore of ex-ante monetary transfers among IP holders), we allow ex-post negotiations about pool formation.

We can compare $\overline{S}$ with the efficient standard $S^*$, or, equivalently, $\overline{k}$ to $k^*$. Note that $k^*$ solves

$$\max_k \max_P \{PD(P - V(S_k))\}.$$

Suppose that $\overline{k} > k^*$. Then $V(S_{\overline{k}}) < V(S_{k^*})$ and reducing $\overline{k}$ both increases overall profit and reduces the number of IP owners sharing this profit, contradicting (6). This yields part (i) of the following proposition:

**Proposition 7** ***(under-inclusiveness).*** *Suppose that functionalities are ranked according to their essentiality. When the within-functionality-competition constraints do not bind,*

*(i) the patent holders covering the top $\overline{k}$ functionalities as given by (6) form a coalition. Furthermore, the standard is never overinclusive: $\overline{k} \leq k^*$.*

*(ii) Suppose that demand for bundle $S$ at price $P$ is given by $F(V(S) - P + \gamma)$, where $\gamma$ is a demand shifter and, as earlier, the hazard rate is monotone ($f/F$ is decreasing). An increase in demand (i.e., an increase in $\gamma$) aggravates under-inclusveness (i.e., $\overline{k}$ decreases or remains the same).*

*Discussion*: A coalition of IP holders as described in this subsection could in principle be thwarted by a user-friendly SSO's setting up a better standard including the patents, but against the will of these IP holders. We are agnostic as to whether such hostile standards, which may be termed "guerilla standardization" or ones that incorporate non-willing participants' intellectual property, are doable: Such efforts have been few and far between in the history of standardization.[29] The difficulties of doing so - the

The sharing of profit within the subsequent pool depends on relative bargaining powers; the prediction relates only to the choice of standard and user price.

[29] One example is the Internet Engineering Task Force's effort to establish a standard on the Virtual Router Redundancy Protocol (VRRP), a computer networking protocol that automatically assigns

difficulty of discerning relevant prior art owned by an uncooperative party (due to the sheer number of outstanding patents and the complexity and ambiguity of patent claims), the need for information about unpatented tacit knowledge in formulating the standards, and the inability to know whether the uncooperative firm would ultimately license the relevant patents on FRAND terms- perhaps forestall SSOs from undertaking such efforts.

## 3.4 Standard designed by users and price discussions: The reverse holdup problem

The analysis of Sections 3.1 through 3.3 points at the inadequacy of ex-post price setting. This section discusses one approach to introducing ex-ante price setting, consisting in letting SSO members discuss prices and make commitments while they design the standard. This approach creates scope for cartelization by implementers/users and expropriation of IP. Suppose that, in reduced form, the SSO's objective function is a convex combination

routers to participating hosts. After the IETF had promulgated a draft standard in 1997, Cisco a few months later argued that this standard closely duplicated its own approach, and that "standardizing on another proposal that so closely mirrors an existing, well established, extensively deployed protocol is out of step with the principles and practices embodied in the IETF," which many interpreted as an implicit threat not to license its key patent on RAND terms unless the Cisco's alternative approach was adopted (http://datatracker.ietf.org/ipr/19/ and http://www.openbsd.org/lyrics.html#35; accessed February 8, 2014). (In 2001, Cisco announced its intention not to assert any claims against any users of the VRRP standard, unless the user was making a patent claim against Cisco; http://lists.graemef.net/pipermail/lvs-users/2001-November/028982.html; accessed February 8, 2014.) The World Wide Web consortium's 2001 draft patent policy also took a step in this direction, noting that "All Essential Claims of a Member with respect to a Recommendation shall be deemed offered for license under a RAND License, unless the Member has, within 60 days after the publication of the Last Call Working Draft, 'opted out' those specific claims by disclosing ... that those Essential Claims will not be available for license under RAND terms" (http://www.w3.org/TR/2001/WD-patent-policy-20010816/#sec-license-genl, section 8.1; accessed February 8, 2014). The policy ultimately adopted in 2003 stripped out this language. We are grateful to an anonymous referee and Robert Barr, former worldwide patent counsel for Cisco Systems, for these examples.

of user surplus and IP owners' profit with weights 1 on user surplus and $\alpha \leq 1$ on profits:

$$W^{SSO}(S,P) \equiv \int_0^{V(S)-P} [V(S) + (\alpha - 1)P - \theta] \, dF(\theta)$$

Assume that the SSO is a monopolist in standard setting and has the bargaining power: The SSO can select a standard and offer a price to each holder of a patent that reads on the standard, and threaten not to enact any standard if the patent holder does not acquiesce (alternatively, it can threaten not to incorporate functionalities covered by IP owners who do not accept the proposed deal). This is obviously an extreme assumption, meant to illustrate the potential for expropriation in a stark way.

**Proposition 8** ***(reverse holdup)*** *Suppose that $\alpha \leq 1$. Then, under SSO bargaining power, the SSO chooses the efficient standard ($S = S^*$) and imposes $P(S^*) = 0$.*

In particular, a balanced SSO (putting equal weight on the two groups: $\alpha = 1$) and a fortiori a user-friendly SSO (putting more weight on users: $\alpha < 1$) have an incentive to choose $S = S^*$ and impose technology price (arbitrarily close to) $P = 0$ so as to maximize diffusion. That is, the SSO can put pressure on the owners of patents reading on the technology and threaten not to incorporate the corresponding functionality into the standard unless they commit to a low licensing price. IP owners then prefer to make a small profit to making no profit at all. More generally, even SSOs that favor IP owners over users will push for low licensing prices so as to ensure a large diffusion of the technology. Only when the SSO is very strongly biased in favor of IP owners will prices be non-expropriative.[30]

[30]See Kovbasyuk (2013) for a detailed analysis of the interaction between credibility and price moderation. In his model, the certifier announces a recommendation, but unlike here does not set a standard.
IP owners may find it difficult to turn to an SSO that defends their interests (a high $\alpha$ SSO). Such

# 4 Structured price commitments

## 4.1 Equilibrium under mandatory price commmitments

This section first shows that price commitments are desirable. It then argues that price commitments are unlikely to emerge spontaneously due to forum shopping.

The "structured price commitments" approach goes as follows:

1. *Price commitments*: Holders of relevant patents non-cooperatively and simultaneously commit to price caps $\overline{p}_i$ on royalties, were the corresponding functionalities later incorporated into the standard.[31]

2. *Standard design*: The SSO's voting rule empowers the users. It is prohibited from contacting IP holders and offering them to pick their technologies in exchange of a renegotiated price: the SSO only selects the standard.

3. *Ex-post pool formation*: The owners of patents that read on the selected standard can, if they wish so, form a pool (allowing independent licensing subject to caps $\{\overline{p}_i\}$) and set a price for the bundle.

4. *Independent licenses*: The patent owners select prices $p_i = p_i^{IL} \leq \overline{p}_i$ for individual licenses.

an SSO may not be trusted by the users to properly ascertain the value of the technology; we here have in mind the kind of situation (studied in our 2006 paper), in which SSOs certify the quality of the technology (say, the users' opportunity cost of implementing the technology is $\theta - \xi$, where as earlier $\theta$ is user-idiosyncratic, and $\xi$ is a common opportunity-cost-shifting or quality parameter that is assessed by the SSO and unknown to the users). There is a tension between the two objectives of securing decent royalty rates and getting users on board: an SSO with a strong IP owner bias is likely to accept technologies of mediocre value to users (low $\xi$ technologies) by pretending that they have high value.

[31] Committing to a price cap that attracts no demand for the licence (e.g., $\bar{p}_i \geq V(S^*)$ or $\bar{p}_i > m_i$), is equivalent of an absence of commitment to the extent that licensors never find it optimal to ex post set a licensing price that attracts no demand, and so such a $\bar{p}_i$ is never binding.

5. *User selection*: Individual users choose whether to adopt the technology, and if so acquire either individual licenses or the bundle from the pool (if relevant).

We continue to assume that if patent holders can increase their joint profit by forming a pool at stage 3, they will do so, and that the sharing of the gains from trade obeys monotonicity in bargaining (see Section 2.4). Note that if functionality $i$ is selected into the standard and patent holder $i$ has set price cap $\overline{p}_i > m_i$, then in the absence of pool formation, patent holder $i$ will reduce his price to $p_i \leq m_i$ so as not to be excluded from the implementation of functionality $i$; furthermore the choice of $\overline{p}_i$ within $[m_i, \infty)$ is irrelevant (in a Markovian sense; see Maskin and Tirole 2001) for that of $p_i$; it does not affect the pool value either. Thus, and in the spirit of the consistency requirement imposed in Section 2.4, it is natural to treat the choice of $\overline{p}_i$ in that range as irrelevant and assume that:

*Irrelevant commitments*: The continuation equilibrium following stage 1 is the same whether patent holder $i$ commits to cap $\overline{p}_i > m_i$ or cap $\overline{p}_i = m_i$ (keeping the other price commitments unchanged).

At stage 2, a user-friendly SSO chooses $S$ so as to maximize user welfare:

$$\max_S \{V(S) - \min\ \{P(S), P^m(S)\}\},$$

where $P(S)$ is the equilibrium total price of standard $S$ given price cap commitments $\{\overline{p}_i\}$ if no pool forms; $P(S)$ corresponds to the competitive prices in the presence of commitments and the absence of cross-functionality substitution opportunities ($\tilde{e}_i \equiv \min\ \{m_i\,, \bar{p}_i\}$ in the notation of Proposition 2). Proposition 9 is a central result of the paper:

**Proposition 9** ***(structured price commitments).*** *Under structured price commit-*

*ments,*

*(i) if* $P^c(S^*) < P^m(S^*)$, *an equilibrium of the structured-price-commitment game involves commitments to the competitive prices* $\overline{p}_i = p_i^c$ *for all* $i$ *and the choice of efficient standard* $S^*$ *(and then no pool is formed). And so the competitive outcome* $(S^*,\ P^c(S^*))$ *prevails. Furthermore, the competitive equilibrium is the only equilibrium if the* $\{e_i\}$ *are uniquely defined for all* $S$.

*(ii) if* $P^c(S^*) \geq P^m(S^*)$, *the competitive benchmark* $(S^*,\ P^m(S^*))$ *is achieved, although the price commitments then in general differ from* $\{p_i^c\}$. *It is an equilibrium for IP owners in* $S^*$ *to commit to ex-post prices* $\bar{p}_i = p_i^*$ *(given by Proposition 4).*

Ex-ante individual price commitments do not guarantee that patent holders will charge the competitive prices $p_i^c$, since their price commitments may affect:

(a) *other patent holders' ex post prices* through "first-mover" effects;

(b) *patent holders' bargaining power in pool formation*; the patent holders may want to lower other patent holders' status-quo profit so as to secure a bigger share of pool profits for themselves;

(c) *technology design* (under standard setting, i.e., in a putty-clay environment); the patent holders may choose their price with an eye on having their patent/functionality included in the standard or other patents/ functionalities excluded.

Nonetheless, Proposition 9 shows that price commitments deliver the competitive benchmark.

Intuitively, price commitments are socially attractive only when the standardization process runs the risk of raising the price $(P^c(S^*) < P^m(S^*))$. Ignoring uniqueness issues (which are tackled in the proof of the Proposition), patentholder $i$ does not gain from committing to a price exceeding the competitive price $p_i^c$: either the latter corresponds to the within-functionality substitution margin ($m_i$) and then the cap is irrelevant, as patentholder $i$ will ex post return to a price below $m_i$ in order not to be ejected from the consumption basket; or it is constrained by the cross-functionality substitution margin ($e_i$) and then not committing to $e_i$ leads users to drop functionality $i$.

Choosing a price cap below the competitive price $p_i^c$, by definition of competitive equilibrium, cannot increase patentholder $i$'s profit if no pool forms, prices of other patents are not affected and standard design remains the same. Consider first the possibility that a pool forms; then by monotonicity in bargaining, patentholder $i$ can gain from deviating from the competitive price only by (sufficiently) reducing other patentholders' profit. However a reduction in $i$'s price promotes the technology and actually benefits other users. Second, a decrease in $p_i$ below its competitive level can be shown not to affect the prices charged in the absence of pool by other patentholders: the latter would then like to increase their prices, but are constrained by their price commitment. Finally, and concerning the design of the standard, we have seen in Section 3 that users, anticipating high overall prices for the technology anyway, include useful, but not-that-essential functionalities, that will later be subject to substantial royalties; intuitively, price commitments have the potential to allow individual IP holders to avoid having to share royalties with greedy holders of low-value-added patents, as the SSO can then usefully part with the corresponding functionalities. The following proof formalizes these loose arguments.

**Proof.** (i) Assume that $P^c(S^*) < P^m(S^*)$ and so a pool is not formed for the standard if competitive prices prevail. Suppose first that all patent holders commit to their competitive price $\bar{p}_j = p_j^c = \min\{m_j^c\ ,\ e_j^c\}$, where the $e_j^c$ are relative to the competitive price vector: The vector $\{e_j^c\}$ is given by equation (2) applied to competitive prices $\{p_j^c\}$.[32] Let

[32] Recall that, while the competitive price vector $\{p_j^c\}$ need not be unique, the essentiality parameters $\{e_j^c\}$ are uniquely defined once the prices $\{p_j^c\}$ are.

us show that the SSO chooses $S^*$. Suppose thus that the SSO chooses $S \neq S^*$. Consider the resulting ex-post equilibrium price vector $\{\tilde{p}_i\}_{i\in S}$ ($\{\tilde{p}_i\}_{i\in S}$ is the set of prices that prevail ex post when no pool is formed, with $\tilde{p}_i \leq p_i^c$ for all $i$).

Either $\tilde{p}_i = p_i^c$ for all $i \in S$, and then the definition of equilibrium (Definition 1) implies that $V(S^*) - P^c(S^*) \geq V(S) - P^c(S)$, and so users do not gain from switching to $S$ if no pool forms; if by contrast a pool forms, charging $P^m(S)$, the fact that $V(S^*) - P^c(S^*) > V(S^*) - P^m(S^*) \geq V(S) - P^m(S)$ implies that users do not benefit from the choice of $S$ rather than $S^*$.

Or there exists $i$ such that $\tilde{p}_i < \overline{p}_i = p_i^c = \min\{m_i\ ,\ e_i^c\} \leq m_i = \min\{m_i\ ,\ \overline{p}_i\}$ (which defines the new constraint on price given the loss of cross-functionality substitution) and so necessarily

$$\tilde{p}_i = \underset{\{p_i | p_i \leq p_i^c\}}{\arg\max} \left\{ p_i D(p_i + \tilde{P}_{-i} - V(S)) \right\}.$$

Then $\tilde{p}_i + \tilde{P}_{-i} = \tilde{P}(S) \geq P^m(S)$, and so a pool forms, leading to price $P^m(S)$ for technology $S$, and thus again no benefit for the users. We conclude that the SSO chooses standard $S^*$ if IP owners commit to their competitive prices.

Let us next show that no patent owner benefits from deviating from the competitive price. Consider $i \in S^*$. Either $p_i^c = m_i$; and then because the ex-post equilibrium prices are still the competitive prices, committing to cap $\overline{p}_i$ above $m_i$ is an irrelevant commitment and does not bring about any extra profit. Setting a cap below $m_i$ is not profitable either; intuitively other patent owners $j$ would then like to either keep $p_j$ constant or raise it, but they cannot raise $p_j$ as they committed to cap $p_j^c$. To show this more formally, recall that $e_j^c$ is no longer relevant ex post and that $\widehat{p}_j = \arg\max\{p_j D(p_i + p_j + \Sigma_{k\in S^*\setminus\{i,j\}} p_k^c - V(S^*))\}$ is higher when $p_i$ is lower. And so $\{p_j^c\}_{j\in S^*\setminus\{i\}}$ is still an ex-post equilibrium. Proposition 2 actually implies that it is the only equilibrium. Finally, note that at $p_i < p_i^c$, $i$'s profit is increasing in $p_i$ when the other IP holders charge their competitive prices. So patent owner $i$ only reduces profit by lowering price below $m_i$.

Or $p_i^c = e_i^c$ is strictly lower than $m_i$ and given by (2'): $V(S^*) - P^c(S^*) = V(S_i) - P^c(S_i)$ for some $S_i$ not including $i$. This means that users can guarantee themselves net value $V(S_i) - P^c(S_i)$ for this particular $S_i$ (prices will at worse be $\{p_j^c\}_{j \in S}$) while if $i$ raises ex post its price commitment to $\bar{p}_i > p_i^c$, users' ex-post utility is smaller than the level that would prevail if they chose $S^*$ or any other standard including $i$ (applying Proposition 2(ii) to $\tilde{e}_i \equiv \min\ (m_i\ ,\ \bar{p}_i)$ and $\widehat{V}(S) = V(S)$ if $S$ is selected as standard and $\widehat{V}(S) = 0$ otherwise). And so functionality $i$ is excluded from the standard. And lowering the price $p_i$ below $p_i^c$ does not affect the prices charged by the other patent holders, by the same reasoning as in the previous paragraph.

To prove uniqueness when the $\{e_i(S)\}$ are uniquely defined for all $S$ (i.e., independent of prices) for any selection of standard $S$, let us show that, for given price commitments $\{\bar{p}_i\}$, the SSO will never choose a standard $S$ leading to user price $p_k > e_k(S)$ for some $k$ in $S$. Necessarily $e_k(S) < m_k$ for this to be the case. Let $\{p_i\}$ and $\{p_i'\}$ denote the (unique) price vectors when $S$ and $S' = S \backslash \{k\}$ are chosen, respectively. Under $S$ and $S'$, respectively, the equilibrium prices are unique (from Proposition 2) and equal to $p_i = \min \{m_i\ ,\ \bar{p}_i\ ,\ \hat{p}_i\}$ and $p_i' = \min\ \{m_i\ ,\ \bar{p}_i\ ,\ \hat{p}_i'\}$ where (for $i \in S'$):

$$\hat{p}_i = \ \arg\max\ \{p_i\ D(p_i + P_{-i}(S') - [V(S) - p_k]\}$$

and

$$\hat{p}_i' = \ \arg\max\ \{p_i\ D(p_i + P_{-i}'(S') - [V(S) - e_k(S)])\}.$$

It is easy to show that the total net price is strictly higher under $S$ than under $S'$ (the proof mimics that of part (ii) of Proposition 2 with IP holder $k$ constrained by $\tilde{e}_k \equiv p_k$ under $S$ and *fictitiously* constrained by $\tilde{e}'_k \equiv e_k(S)$ under $S'$, as $S'$ is equivalent to $S$ but with a cap equal to $e_k(S)$ for $k$). Because $\bar{p}_i = 0$ for $i \notin S$, then users can obtain net price for $S^*$ at most equal to $P(S) - V(S^*) < P(S) - V(S)$ and so the SSO would rather choose standard $S^*$ than standard $S$, a contradiction. Hence $S = S^*$. And because prices cannot exceed the essentiality parameters for the chosen standard, $P(S^*) \leq \Sigma_{i \in S^*}$ min $\{m_i \; e_i(S^*)\} = P^c(S^*)$.

(ii) Regardless of price commitments, the SSO can always pick standard $S^*$. From Proposition 2, in the absence of pool, the continuation game in individual license prices has a unique equilibrium. After, possibly, the formation of a pool,[33] the total price will not exceed $P^m(S^*)$. And so users can guarantee themselves net price $P^m(S^*) - V(S^*)$, i.e., their welfare in the competitive benchmark.

However, when $P^c(S^*) > P^m(S^*)$, the competitive prices need not be equilibrium price commitments. To see this, consider the symmetric, two-functionality case with $S^* = \{1, 2\}$ and

$$p^m \equiv \frac{P^m(2)}{2} = \text{arg max } \frac{PD(P - V(2))}{2} < e < \min \{m, \hat{p}\}.$$

The competitive price is $P^c(S^*) = 2e$, and yields $eD(2e - V(2))$ to each IP owner. Suppose that the ex-ante competitive prices are the equilibrium price caps and that IP owner $i = 1$ raises his price commitment to $\bar{p}_i = e + \varepsilon$ for a small enough $\varepsilon$. Let us first show that the SSO still chooses standard $S^*$. After the formation of a pool, the net price for standard $S^*$ will be $P^m(2) - V(2)$. If the SSO selects $S = \{2\}$ instead, the price will be min $\{e,$

[33]If the ex-post price exceeds $P^m(S^*)$, firms will guarantee themselves the monopoly profit by opting for a pool with independent licensing and unbundling, with price $p$ per patent such that $\Sigma_{\{m_i \leq p\}} m_i + [\#\{i | p < m_i\}]p = P^m$. The unique equilibrium is then $p_i^{IL} = m_i$ if $m_i \leq p$ and $p_i^{IL} = p$ (or $\geq p$) if $p < m_i$. Side transfers then take place, that depend on the respective bargaining powers.

$\tilde{p}^m\}$ where

$$\begin{aligned}\tilde{p}^m &= \arg\max_p \{pD(p - V(1))\} = \arg\max_p \{pD(p + e - V(2))\} \\ &= \arg\max_P \{(P - e)D(P - V(2))\} - e \geq \hat{p}\end{aligned}$$

This optimization defines a function $\tilde{p}^m(e)$ with $\partial\tilde{p}^m/\partial e \in (-1, 0)$ and $\tilde{p}^m(\hat{p}) = \hat{p}$. And so min $\{e, \tilde{p}^m(e)\} = e$. And because

$$e - V(1) = 2e - V(2) > P^m(2) - V(2),$$

the users prefer $S^*$. Finally, note that IP owner 1 raises his pre-pool-formation profit:

$$\frac{d}{d\varepsilon}[(e + \varepsilon)D(2e + \varepsilon - V(2))] > 0 \qquad \text{(since } e < \hat{p}\text{)},$$

and lowers IP owner 2's pre-pool-formation profit.

$$\frac{d}{d\varepsilon}[eD(2e + \varepsilon - V(2))] < 0,$$

and so from monotonicity in bargaining, IP owner 1 increases his profit by raising his price above $e$.

Finally, we show that in the general case it is an equilibrium for all firms to commit to ex-post prices $p_i^* = \min\{m_i\ , \hat{p}\}$ for $i \in S^*$.

(a) Suppose that $i$ deviates from $p_i^*$ and $S^*$ is chosen as the standard. By definition of the optimal ex-post price $p_i^*$, firm $i$ cannot deviate and increase its pre-pool-formation profit. It could reduce the others' pre-pool-formation profits by *raising* its price and thus decreasing demand. However, neither $\bar{p}_i > m_i$ nor $\bar{p}_i > \hat{p}$ is credible, as $i$ attracts no sales in the former case and $\bar{p}_i > \hat{p}$ is not a best reaction to $\{p_j^*\}$ in the latter case. So $\bar{p}_i > p_i^*$ is ex post modified into $p_i^*$ if the pool does not form.

(b) By choosing standard $S^*$, users obtain net price

$$P^m(S^*) - V(S^*) \leq P^c(S^*) - V(S^*) \leq P^c(S) - V(S) \leq P^*(S) - V(S)$$

for all $S$. Either $P^*(S) \leq P^m(S)$ and then the conclusion follows; or $P^*(S) > P^m(S)$ and renegotiation of prices post choice of standard $S$ leads to net price $P^m(S) - V(S) \geq P^m(S^*) - V(S^*)$.

Finally, combining the reasonings in (a) and (b) so far, one can show that if $i$ deviates from $p_i^*$ to some $\bar{p}_i$ , then $S^*$ is still selected due to the fact that $V(S^*) - P^m(S^*) \geq V(S) - \min\{P^m(S), P^c(S)\}$ for all $S$, in the case under consideration. Pick some $S$; either there exists $j$ such that $\hat{p}(S) \leq m_i$ , and then $P^c(S) \geq P^m(S)$ and so choosing $S^*$ is optimal. Or $\hat{p}(S) > m_j$ for all $j \in S$, and so $P^c(S) = \sum_{j \in S} m_j$. And then the value of choosing $S$ is not altered by $i$'s deviation. ■

In our framework, there is no need to impose FRAND. The price commitments deliver the ex-ante competitive benchmark and adding a promise of "fair prices" serves no purpose. In practice, though, standard setting organizations may make mistakes; they (and perhaps the IP holder himself) may fail to identify an important patent as relevant to the standard. Ex post, this may result in a hold up of the standard. In our view, therefore, structured price commitments do not obviate the need for FRAND. Structured price commitments bear the brunt of the commitment and cover identified functionalities; the FRAND commitment somewhat makes up for the unavoidable shortcomings of the discovery process.

## 4.2 Forum shopping and the (non-) emergence of structured price commitments in the marketplace

We now consider a context in which a user-oriented SSO adopts a mandatory-price-commitment rule, while the IP owners can go to an alternative user-oriented SSO that does not require such price commitments. Assuming that the competitive prices emerge under standard setting by the SSO with a mandatory-price-commitment rule, do price commitments emerge when the IP owners can engage in forum shopping?

To answer this question, let us start with the symmetric technology/symmetric equilibrium of Proposition 1(iv) (with $S^* = \{1, \cdots, n\}$), as this guarantees that IP holders have congruent interests when choosing an SSO. Price commitments are irrelevant if the competitive price is the level $m$ corresponding to within-functionality substitution.[34] So let us assume that within-functionality substitution is not binding ($m$ large). If the competitive per patent price $p^c$ is given by (2) ($p^c = e$ where $V(S^*) - ne = \max_S \{V(S) - \{\#S)e\}$), and $np^c < P^m(S^*)$, a mandated price commitment reduces per-patentholder profit and therefore patent holders strictly prefer to be certified by the SSO that does not require such price commitments. If $np^c \geq P^m(S^*)$, they are indifferent between the two SSOs but price commitments then are not needed to achieve the competitive benchmark.

To study the asymmetric case, let us consider the two-functionality case ($n = 2$ and $S^* = \{1, 2\}$), and compare the preferences of the two patentholders. Again, assume for

[34]Because by assumption $m \leq e$, $V(S^*) - nm \geq V(S) - km$ for any standard $S$ with $k$ functionalities. And so the only purpose of selecting an underinclusive standard would be to induce at least one of the owners of patents reading on standard $S$ to lower his price below $m$. However $(k-1)m - V(S) \geq (n-1)m - V(S^*)$ and so

$$\begin{aligned} \arg\max \ \{pD(p + (k-1)m - V(S))\} &\geq \arg\max \ \{pD(p + (n-1)m - V(S^*))\} \\ &\geq m \end{aligned}$$

where the last inequality stems from the fact that $m$ is the competitive price.

simplicity that there are no opportunities for within-functionality substitution ($m_i$ large). As in the symmetric case, price commitments are irrelevant for the users if the competitive price exceeds the monopoly price (here $p_1^c + p_2^c \geq P^m(S^*)$) since the outcome will deliver the monopoly profit in both cases. IP owners have antagonistic interests, though: If $p_1^c > p_2^c$ and $p_2^c = e_2$ (otherwise $p_1^c = p_2^c$), patent holder 1 prefers price commitments since he is in a better bargaining position than patent holder 2 in the negotiation for a pool. By contrast, patent holder 2 prefers the absence of price commitment, which makes the two patents de facto equally important.

Now assume that $p_1^c + p_2^c < P^m(S^*)$. Then price commitments reduce total profit. Patent holder 2 is always hurt when price commitments are mandated.[35] By contrast, patent holder 1 faces a trade-off between a lower overall profit and a higher share of this profit: He prefers the absence of price commitment if and only if

$$p_1^c D\left(p_1^c + p_2^c - V(S^*)\right) \leq \frac{P^m(S^*)}{2} D\left(P^m(S^*) - V(S^*)\right). \tag{7}$$

Thus for a given value $V(S^*)$ of the technology, patent holder 1 is more eager to avoid price commitments, the less essential his patent (the lower $e_1$ is) and the more essential the other patent (the higher $e_2$ is).

**Proposition 10** ***(market non-emergence of price commitments)***. *When the competitive price is smaller than the monopoly price,*

*(i) in the symmetric case, patent holders prefer the absence of price commitment and so choose to have their technology certified by an SSO that does not require price commitments;*

[35] $P^m D(P^m - V(S^*)) > P^c D(P^c - V(S^*))$ implies that $\frac{P^m}{2} D(P^m - V(S^*)) > \frac{P^c}{2} D(P^c - V(S^*)) > p_2^c D(P^c - V(S^*))$.

*(ii) in the asymmetric case and with $n = 2$ and no possibility of within-functionality substitution, the owner of the less important patent prefers not being forced to commit to a price; the owner of the more important patent prefers to avoid a price commitment if and only if $P^c(S^*) < P^m(S^*)$ and (7) holds.*

Proposition 10 sheds light on a recent development. An ambitious response to the commitment problem has been the effort of the international trade association VITA, which focuses on standards that govern modular embedded computer systems, to overcome opportunistic behaviour by owners of standard-essential patents. VITA mandated that each member of a standards working group must indicate all patents or patent applications that may become essential to the workings of a future standard, as well as the highest royalty rates and the most restrictive terms under which they would license these patents. This policy shift, as well as similar, even less successful efforts by the Institute of Electrical and Electronics Engineers (IEEE) and the European Telecommunications Standards Institute (ETSI), encountered stiff resistance from intellectual- property-owning firms and was not very effective in changing the overall standardization process (see Masoudi 2007 for an interesting view from the antitrust authorities' side and Lerner and Tirole 2014 for a further policy discussion).

Forum shopping is an obstacle to the emergence of structured price commitments. This analysis suggests that price commitments must be mandated, since they will not necessarily come about spontaneously.

# 5 Concluding remarks

The paper constitutes a first pass at a formal analysis of standard-essential patents. Its main insights were laid out in the introduction, so let us conclude with a few thoughts about future work.

First, one would want to extend the analysis to multidimensional price commitments. A complication, which arises under structured price commitments as well as the FRAND requirement or alternative regulations, is that IP holders may want to charge different rates to, or use different units of measurement of license usage for, different classes of users (while abiding by the non-discrimination requirement within a class). We conjecture, but have not verified that multidimensional price commitments would not affect the key insights of this paper. Price competition then takes a Ramsey form, in which the IP owner competes through a vector of prices that must overall deliver a positive surplus to users. If so, the difficulty may relate more to the potential complexity of price structures. There will be in general a trade-off between the granularity of defined user classes and the complexity of the scheme. This trade-off is specific neither to structured price commitments nor to the standard setting context more generally. A particularly interesting instance of complex price commitments relates to uncertainty about future states of nature. Presumably, precise contingent commitments are largely unfeasible and so the properties of price cap commitments under uncertainty about future demand or technological evolution remain to be investigated.

Second, standards evolve; backward compatibility imperatives often imply that the inclusion of one's patents in a standard has a long-lasting impact on profitability. Conversely, SSOs must anticipate the likely (endogenous) evolution of available technologies when selecting a standard. The study of dynamic standard design lies high in priority in the research agenda.

Third, one would want to account for the puzzling fact that patent pools sometimes use patent counting (shares are related to the number of patents contributed to the pool). While Section 3 has provided some explanation for why patent holders may (inefficiently) receive equal shares in a patent pool despite very asymmetric contributions to the technology, it does not quite solve the patent counting puzzle: for, owning two essential patents is in theory equivalent to owning a single one. Random bypass opportunities may offer some hint concerning the resolution of this puzzle.[36]

Fourth, we could allow for coordinated effects. Presumably unbundling might then have additional benefits in terms of preventing pools from facilitating collusion, as in Rey-Tirole, but this certainly requires a separate analysis.

We leave these and the many other open topics on standard setting to future research.

[36] An alternative explanation for patent counting was suggested to us by Andrey Malenko. The idea is that the owner of (say,) two essential patents can threaten to spin off one of them, thereby creating an extra gatekeeper for the technology. Thus, the owner of multiple standard-essential patents has substantially more bargaining power than the owner of a single standard-essential patent.

# Appendix

# Proof of Proposition 1

(i) *Efficient design.* Suppose that the competitive prices sustain $\mathcal{T}$; then because $p_i = 0$ for $i \notin \mathcal{T}$, $P(S^*) \leq P(\mathcal{T})$ and so $P(S^*) - V(S^*) < P(\mathcal{T}) - V(\mathcal{T})$, a contradiction.

(ii) *Existence.* We fix prices $p_j = 0$ for $j \notin S^*$, and consider the vector $\boldsymbol{p} \equiv \{p_i\}_{i \in S^*}$. Let

$$\mathcal{P} \equiv \{\boldsymbol{p} \,|\, 0 \leq p_i \leq V(S^*) \ \text{ for all } \ i \in S^*\}.$$

Consider the mapping $\boldsymbol{p} \to \mathring{\boldsymbol{p}}$, where

$$\mathring{\boldsymbol{p}}_i = \min \{m_i, e_i(\boldsymbol{p}), \widehat{p}_i(\boldsymbol{p})\},$$

$$e_i(\boldsymbol{p}) \equiv \max \ \{0, V(S^*) - P(S^* \backslash \{i\}) - \max_{\{S | i \notin S\}} \{V(S) - P(S)\}\}$$

and

$$\widehat{p}_i(\boldsymbol{p}) = \arg\max \ \{p_i D(p_i + P(S^* \backslash \{i\}) - V(S^*))\}.$$

This mapping from compact convex set $\mathcal{P}$ into itself is continuous. From Brouwer's fixed-point theorem, it admits a fixed point.

(iii) *Unique unconstrained price.* For each $k \in S^*$, let $P_{-k} \equiv \Sigma_{\ell \in S^* \backslash \{k\}} p_\ell$ denote the total price charged by other patent holders in the efficient consumption basket. Let $r$ denote the reaction function:

$$r(P_{-k}) \equiv \arg\max_{p_k} \ \{p_k D(p_k + P_{-k} - V(S^*))\} \tag{8}$$

with $-1 < r' < 0$ from the log-concavity of $F$. Now, if patent holders $i$ and $j$ are both unconstrained,

$$p_i = r(P_{-i}) \text{ and } p_j = r(P_{-j}).$$

Because $r' > -1$, this precludes $p_i + P_{-i} = p_j + P_{-j} = P(S^*)$ unless $p_i = p_j$.

(iv) *Unique symmetric equilibrium in symmetric case.* Straightforward.

# Multiplicity of competitive equilibria

*Example 1.* First, individual prices may not be uniquely defined, for a reason that is similar to that creating multiplicity in the Nash demand game: Suppose that there are three patents, 1, 2 and 3, that $S^* = \{1, 2, 3\}$ that $V(\{1, j\}) = V(\{1\})$ for $j \neq 1$, and that $V(\{2, 3\}) = 0$. That is, patent 1 is essential, and patents 2 and 3 are perfect complements to create an add-on to patent 1. Furthermore suppose that there is no within-functionality substitution feasibility for any patent ($m_i \geq V(S^*)$ for all $i$). Then prices $p_2$ and $p_3$ must satisfy

$$V(S^*) - (p_1 + p_2 + p_3) = V(\{1\}) - p_1,$$

but the split between $p_2$ and $p_3$ is indeterminate. Note that $e_2$ (and similarly $e_3$) is not uniquely defined; only $e_2 + p_3$ is, and so $e_2$ depends on $p_3$.

*Example 2.* Second, and more substantially, the total Nash price itself may not be unique. To see this, take the previous three-patent example with $S^* = \{1, 2, 3\}$ and no within-functionality switching opportunities, but assume now that

$$V(S^*) > V(\{2\}) = V(\{3\}) = V > 0 = V(S) \text{ for all other } S.$$

Assuming that constraint (2') is the binding one (one can always choose the demand function to guarantee this), prices must satisfy $p_1 + p_2 = p_1 + p_3 = V(S^*) - V$ (here $e_1$ is not uniquely defined; only $e_1 + p_2 = e_1 + p_3$ is); and so $p_2 = p_3$. Assuming that $V(S^*) \geq 2V$, the total price $p_1 + p_2 + p_3$ can take any value in $[V(S^*) - V, V(S^*)]$.

# Proof of Proposition 2

(i) *Uniqueness*. Consider a set of competitive prices, and split the functionalities into groups $I_1$ (constrained price: $p_i = \widetilde{e}_i$) and $I_2$ (unconstrained price: $p_i < \widetilde{e}_i$) (either group may be empty). From the proof of part (iii) of Proposition 1, all prices in $I_2$ are equal to some $\widehat{p}$. Consider the function $r(\widehat{p})$ defined by:

$$r(\widehat{p}) \equiv \arg\max_{\{p\}} \left\{ pD\left( \Sigma_{\{i|\widetilde{e}_i \leq \widehat{p}\}} \widetilde{e}_i + (\#(i|\widetilde{e}_i > \widehat{p}) - 1)\widehat{p} + p - V(S^*) \right) \right\}.$$

The function $r$ is continuous (although not smooth) and (weakly) decreasing. It therefore has a unique fixed point in $[0, V(S^*)]$. The Nash prices are $p_i = \min\{\tilde{e}_i, \hat{p}\}$.

(ii) *Comparative statics*. Let $\tilde{E}(S) = \Sigma_{i \in S} \widetilde{e}_i$ for an arbitrary $S$. The equilibrium price for given $\{\tilde{e}_i\}_{i \in S^*}$ is equal either to $\tilde{E}(S^*)$ if for all $i$, $\tilde{e}_i \leq r(\tilde{E}(S^* \backslash \{i\}))$; or to $[X(\widehat{p}) + [\#S^* - k(\widehat{p})]\widehat{p}]$ otherwise, where $k(\widehat{p})$ is the number of $i$ such that $\widetilde{e}_i \leq \widehat{p}$, $X(\widehat{p}) \equiv \Sigma_{\{i \in S^* | \tilde{e}_i \leq \hat{p}\}} \tilde{e}_i$ and $\widehat{p}$ is uniquely defined by

$$\widehat{p} = r(X(\widehat{p}) + [\#S^* - [k(\widehat{p}) - 1]]\widehat{p}).$$

Simple computations show that in both cases

$$\frac{d}{dX}(X + [\#S^* - k(\widehat{p})]\widehat{p}) = \frac{1 + r'}{1 - [\#S^* - [k(\widehat{p})]]} > 0 \quad \text{since} \quad -1 < r' < 0.$$

Therefore as the $\tilde{e}_i$ are reduced, the total price (weakly) decreases.

(iii) *Decreasing incremental contributions.* Consider functionality $i \in S^*$:

$$V(S^*) - \Sigma_{j \in S^*}\, p_j = V(S_i) - \Sigma_{k \in S_i}\, p_k$$

for some $S_i$ such that $i \notin S_i$ (and $S_i \subset S^*$ since $S^* = \{1, \cdots, n\}$).

Because $p_j \leq V(S^*) - V(S^* \backslash \{j\})$ for all $j \in S^*$,

$$V(S^*) - \Sigma_{j \in S^*} p_j \geq [V(S^*) - \Sigma_{k \in S_i} p_k] - [\Sigma_{j \notin S_i} [V(S^*) - V(S^* \backslash \{j\})]].$$

But decreasing incremental contributions imply that

$$\Sigma_{j \notin S_i} [V(S^*) - V(S^* \backslash \{j\})] \leq V(S^*) - V(S_i)$$

with strict inequality unless $S_i = S^* \backslash \{i\}$. We thus obtain a contradiction unless $S_i = S^* \backslash \{i\}$. Finally, note that by the same reasoning $V(S^*) > \Sigma_{i \in S^*} e_i$. And so, the equilibrium is unique.

# Proof of Proposition 3

(i) Note that $\{S^*, P^m(S^*)\}$ delivers the highest aggregate profit for the IP owners. Define shares $\{\alpha_i\}_{i\in S^*}$ in the patent pool such that all patent holders gain from forming a pool:

$$\alpha_i P^m(S^*)D(P^m(S^*) - V(S^*)) \geq p_i^c D(P^c(S^*) - V(S^*)).$$

From the definition of monopoly profit, one can indeed find such $\alpha_i$'s such that $\Sigma_{i\in S^*}\alpha_i \leq 1$.

Suppose that the pool with the functionalities in $S^*$ is formed, with $\alpha_i$ satisfying the condition above, and that the pool charges $P^m(S^*)$. Suppose further that each pool member charges $p_i^{IL} = p_i^c$ for individual licenses and so in equilibrium users buy the bundle from the pool. By definition of the competitive prices, a deviation from this individual license price cannot increase profit beyond $p_i^c D(P^c(S^*) - V(S^*))$ (assuming that users opt for a bundle of independent licenses, which incidentally requires that $p_i^{IL} \leq p_i^c - [P^c(S^*) - P^m(S^*)]$), and so there is no profitable deviation.

We just described an equilibrium of the independent-licensing game. What about uniqueness? Suppose that there exists another equilibrium with selection $S^*$ and total price $P^{IL}(S^*)$ for independent licenses, such that $P^{IL}(S^*) < P(S^*)$ (by the now-standard reasoning, $p_i^{IL} = 0$ for $i$ not in the basket selected by users implies that users must select $S^*$). Then $\{p_i^{IL}\}$ must be competitive equilibrium prices, a contradiction if the competitive price is unique or the selection consistent.

To understand the need for a consistent selection in the case of multiple competitive prices, consider the Appendix' Example 2 above, and focus on the socially most efficient competitive equilibrium ($p_2 = p_3 = 0$; $p_1 = V(S^*) - V$; $V(S^*) - P(S^*) = V$) and the socially most inefficient one ($p_2 = p_3 = V$; $p_1 = V(S^*) - 2V$; $V(S^*) - P(S^*) = 0$). Choose the demand function so that $P^m$ =arg max $\{P\ D(P - V(S^*))\} \in (V(S^*) - V,\ V(S^*))$, and suppose that the latter equilibrium prevails in the absence of a pool and that the former equilibrium is selected when a pool is formed. This equilibrium switch implies that the pool is undercut through individual licenses despite the fact that it lowers price, and that the firms may not want to form a welfare-increasing pool.

Last, it can be shown that when the essentiality parameters are unique, an unbundling requirement does not destabilize welfare-decreasing pools. The pool can for instance set

$$p_i^P \equiv [\min\ \{m_i\ ,\ e_i\}]P^m(S^*)/P^c(S^*) < \min\ \{m_i, e_i\}.$$

Proposition 2 then implies that the equilibrium in independent licenses is unique and delivers total price $P^m(S^*)$.

(ii) The condition $P^c(S^*) < P^m(S^*)$ implies, as we have seen, that all prices $p_i^c$ are determined by either (1) or (2'). Consider pool $S = S^*$ charging a price $P(S^*) > P^c(S^*)$. Then we claim that all members of the pool charging their competitive prices for their independent licenses is an equilibrium. By definition of competitive prices, charging price $p_i^{IL} \neq p_i^c$ does not increase profit if users keep buying individual licenses instead of the bundle offered by the pool. Hence, the motive for deviating from this competitive price configuration is to make individual licenses as a whole less attractive and to thereby shift the demand to the pool bundle and receive royalties from the pool. However, either $p_i^c = m_i$ and then if $p_i > p_i^c$, users can still secure $V(S^*) - P^c(S^*)$ by substituting within the functionality; or $p_i^c$ is given by (2') satisfied with equality, and then if $p_i > p_i^c$ , users can again secure $V(S^*) - P^c(S^*)$, this time by substituting among functionalities. This reasoning more generally applies to any pool/bundle $S$ such that $V(S) - P(S) < V(S^*) - P^c(S^*)$: as long as all charge $p_i = p_i^c$, the users can guarantee themselves $V(S^*) - P^c(S^*)$

even in case of a unilateral deviation.

(iii) To prove part (iii), let $\tilde{e}_i' \equiv \min\{m_i, e_i, p_i^P\} \leq \tilde{e}_i \equiv \min\{m_i, e_i\}$. Proposition 2 implies, first, that the continuation equilibrium in independent licensing prices $\{p_i^{IL}\}$ is unique, and second, that the total price cannot exceed its level in the absence of pool. So IP holders can neither increase their aggregate profit nor hurt users by forming a pool. So IP holders can neither increase their aggregate profit nor hurt users by forming a pool. Therefore the outcome is the competitive equilibrium.

# Proof of Proposition 4(ii)

(i) This is basically an application of Propositions 1 and 2, with $\tilde{e}_i \equiv m_i$ for all $i$ (thus essentiality is uniquely defined). If $I_2(S)$ (as defined in the proof of Proposition 4) is empty, then $P^*(S) = \Sigma_{i \in S}\, m_i \geq P^c(S^*)$. So suppose $I_2(S)$ is not empty and has $k^*(\hat{p}) = \#\{i|\hat{p} < m_i\}$ elements. We know from Proposition 4 that

$$\hat{p}^* = r_S(X^*(\hat{p}) + (k^*(\hat{p}) - 1)\hat{p}^*),$$

where $r_S$ denote the reaction curve corresponding to demand $P(S) \to D(P(S) - V(S))$ (we know that $-1 < r_S' < 0$), and $X^*(\hat{p}) = \Sigma_{\{i|m_i \leq \hat{p}\}}\, m_i$. Similarly, letting $k^c(\hat{p}) = \#\{i|\hat{p} < \min\{m_i, e_i\}\}$, one can define

$$X^c(\hat{p}) = \Sigma_{\{i|\min\{m_i,e_i\} \leq \hat{p}\}} \min\{m_i, e_i\} \leq X^*(\hat{p}),$$

and $\hat{p}^c = r_S\left(X^c(\hat{p}) + (\#S - k^c(\hat{p}))\,\hat{p}^c\right)$.

Simple computations show that in both cases $\frac{d}{dX}\left(X + (\#S - k)\hat{p}\right) = \frac{1+r_S'}{1-(\#S-k)r_S'} > 0$. Finally, start at $X = X^*(\hat{p})$ and reduce $X$; then $\hat{p}$ increases, but total price decreases.

And so $P^c(S) \leq P^*(S)$.

(ii) Either $P^*(S) \geq P^m(S)$ and then indeed

$$V(S^*) - \mathcal{P}(S^*) \geq V(S^*) - P^m(S^*) \geq V(S) - P^m(S) = V(S) - \mathcal{P}^*(S).$$

Or $P^*(S) < P^m(S)$ and then necessarily $P^*(S) = \sum\limits_{i \in S} m_i \geq P^c(S)$. Then

$$V(S^*) - \mathcal{P}(S^*) \geq V(S^*) - P^c(S^*) \geq V(S) - P^c(S) \geq V(S) - P^*(S) = V(S) - \mathcal{P}(S^*).$$

# Proof of Proposition 5

Suppose standard $S$ is selected. We therefore are only interested in the *ex-post* prices of patents in $S$. Let $p_i^*$ denote the ex-post Nash prices in the absence of pool. If $p_i^* < m_i$ for some $i$, then $P^c(S) \geq P^m(S)$, and so a pool can only benefit users. Suppose therefore that $p_i^* = m_i$ for all $i \in S$. If $\Sigma_{i \in S}\ m_i \geq P^m(S)$, then again a pool can only benefit users. If $\Sigma_{i \in S}\ m_i < P^m(S)$, users can always recreate bundle $S$ at cost $\Sigma_{i \in S}\ m_i$ and so the pool cannot raise price.

# Proof of Proposition 6

Either $\mathcal{P}^*(S) = P^m(S)$; because $V(S^*) - P^m(S^*) \geq V(S) - P^m(S)$ for all $S$, $S$ cannot be preferred to $S^*$. Or (from equation (4) in the body of the paper) $\mathcal{P}^*(S) = \Sigma_{k \in S}\ m_k$. If $S \supset S^*$, $V(S) - \Sigma_{k \in S}\ m_k \leq V(S^*) - \Sigma_{k \in S^*}\ m_k$. So the standard cannot be overinclusive. Suppose next that $i$ and $j$ are defined as in part (ii) of the statement of the proposition. If $m_i \leq m_j$ , users could substitute $i$ for $j$ and create standard $S' = S \cup \{i\} \backslash \{j\}$, creating value $V(S') > V(S)$ at price $P(S') = P(S) - (m_j - m_i) \leq P(S)$.

To illustrate the possibility of underinclusiveness, suppose that there are two functionalities $S^* = \{1, 2\}$, that $m_1 \geq V(S^*)$ and $m_2 = 0$, and finally that $V(S^*) - V(\{2\}) < P^m(S^*)$; then users prefer $\{2\}$ to $S^*$. To illustrate the fact that functionality ranks are not necessarily respected, suppose again that $n = 2$ and

$$V(S) \equiv \phi(\Sigma_{i \in S}\ e_i) - c(\#S)$$

where $\phi$ is increasing and concave, $c$ is the cost of including an extra functionality, $e_1 > e_2$, and

$$\phi(e_2) - c > 0 \ \text{ and } \ \phi(e_1 + e_2) - c < \phi(e_2).$$

So $S^* = \{1\}$. However if $m_2 = 0$ and

$$\phi(e_1) - \min\ \{m_1\ ,\ P^m(S^*)\} < \phi(e_2),$$

then users select $S = \{2\}$.

# Proof of Proposition 7(ii)

Let

$$\Delta_k(\gamma) \equiv (k+1) \max_P \{PF(V(S_k) - P + \gamma)\} - k \max_P \{PF(V(S_{k+1}) - P + \gamma\},$$

where, $S_k$ denotes the set of the first $k$ functionalities. It is easy to check that

$$\Delta'_k(\gamma)\Big|_{\Delta_k(\gamma)=0} \quad \propto \quad \frac{f(V(S_k)-P^m(S_k)+\gamma)}{F(V(S_k)-P^m(S_k)+\gamma)} - \frac{f(V(S_{k+1})-P^m(S_{k+1})+\gamma)}{F(V(S_{k+1})-P^m(S_{k+1})+\gamma)}.$$

Furthermore, Proposition 7 implies that for relevant values, $k$, $k+1 \leq k^*$, and so $V(S_{k+1}) \geq V(S_k)$, implying

$$V(S_{k+1}) - P^m(S_{k+1}) \geq V(S_k) - P^m(S_k).$$

The monotonicity of the hazard rate implies that $\Delta'_k(\gamma)$ is non-negative whenever $\Delta_k(\gamma) = 0$; and so there exist $\gamma_k$ such that $k$ is preferred to $k+1$ if and only if $\gamma \geq \gamma_k$.

# Proof of Proposition 8

For an arbitrary standard $S$, consider the program:

$$\max_{\{P\in\mathcal{P}(S)\}} \left\{W^{SSO}(S,P)\right\},$$

where $\mathcal{P}(S)$ is the set of feasible total prices for standard $S$, $\mathcal{P}(S) = [0, \Sigma_{i\in S} m_i]$. Note that

$$\begin{aligned} W^{SSO}(S,P) &\leq \int_0^{V(S)-P} [V(S)-\theta]\, dF(\theta) \\ &\leq \int_0^{V(S)} [V(S)-\theta]\, dF(\theta) = W^{SSO}(S,0) \end{aligned}$$

since $V(S) \geq \theta$ for all $\theta$ such that $V(S) \geq \theta + P$. And so

$$\max_{\{S,\ P\in\mathcal{P}(S)\}} \left\{W^{SSO}(S,P)\right\} \quad \Longleftrightarrow \quad \max_{\{S\}} \left\{W^{SSO}(S,0)\right\}.$$

Furthermore

$$W^{SSO}(S,0) = \int_0^{V(S)} [V(S) - \theta]\, dF(\theta)$$

is maximized for $S = S^*$.

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