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STANDARD-ESSENTIAL PATENTS

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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 the 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 intense litigation activity. This paper builds a framework for the analysis of SEPs, identi.es several types of inefficiencies attached to the lack of price commitment, shows how structured price commitments restore competition, and analyzes whether price commitments are likely to emerge in the marketplace.

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1 Introduction

Standard-essential patents. 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 (if their patents dominate some of the functionalities embodied in the standard) or just to develop a competitive edge through their familiarity with the technology.

Standard setting organizations (SSOs) in essence perform three functions. The discovery or engineering 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]

SSOs' third and controversial regulation function results from the second. In an attempt to curb the monopoly power that they create, 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 intense litigation activity. As both the antitrust practice and the legal literature[2] emphasize, "fair and reasonable" must reflect the outcome of ex-ante technology competition, not of the manufactured ex-post monopoly situation. As Judge Posner recognized in Apple vs. Motorola, it is fallacious to take an ex-post perspective.[3]

The informational difficulties faced by courts when assessing whether patents are essential and whether royalties are "fair and reasonable" are familiar from the treatment of patent pools. As has been repeatedly noted in the latter context, it is hard to know

[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] "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).

whether patents are complements or substitutes, i.e., how essential they are. Indeed, one might say that "standards' cemeteries are full of essential patents".[4] To make things worse, the complementary/substitutability pattern depends on licensing prices and changes over time as technology and applications evolve. Finally, informational problems are compounded in the case of standard-setting by the after-the-fact nature of the assessment.

Paper's contribution. Despite their prominence in business and antitrust economics, the essentialization and regulation functions have received scant theoretical attention. This paper builds a framework in which they can start being analysed, provides a precise identification of the inefficiencies attached to the lack of price commitment, and suggests a policy reform that restores the ex-ante competition called for in the literature and the policy debate.

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 do not specify patents, but rather functionalities, 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. For each functionality, furthermore, one or several patents read on the functionality. In other words, a functionality is characterized by two attributes: how essential the functionality is relative to the overall technology, and how intense is within-functionality competition. Finally, 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 and in particular is not constrained by the need to coordinate his technological choice with those of the other users. The section studies existence and uniqueness of the competitive equilibrium and 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 by contrast is devoted to the study of the "putty-clay" version of the same environment. In that version, strong network externalities require coordination

[4] To paraphrase de Gaulle's "The graveyards are full of indispensable men."

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 (malthusianist). 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 morph the technology into one that differs from the competitive benchmark. Intuitively, users prefer to include functionalities on which several competing patents read rather than more essential, but monopolized ones that will command high ex-post prices.

Section 3 further shows that price discussions within the standard setting process run the risk of expropriation of IP holders, as even balanced SSOs will "blackmail" IP owners to accept low prices in exchange for their functionalities' being selected into the standard.

Section 4 studies whether structured price commitments can undo the inefficiencies unveiled in Section 3. We propose that price discussions continue to be prohibited, but that after a discovery phase, IP holders non-cooperately announce price caps on their offerings, were their IP to be included into the standard. 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.

Relationship to the literature.

The paper is related to several strands of the literature. The first is the large legal literature on standard essential patents. This literature first grew out of two cases that triggered 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 proposal 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).

Second, we have already noted the close links between standard setting and patent pools. Both institutions face similar informational difficulties regarding essentiality. The lack of data to measure the essentiality and the evolving nature of essentiality both make it difficult to form an opinion as to what specific patents are contributing to a technology. There are therefore large benefits to finding "information-free screens". In the context of patent pools, such a screen consists of regulatory requirements that do not hinder the functioning of beneficial (price-reducing) pools and restore competition in the case of detrimental (price-augmenting) pools. In the absence of coordinated effects (tacit collusion), independent licensing, i.e., the ability for IP holders to keep ownership of their patents and to market them independently of the pool, can perform this perfect-screen function (Lerner-Tirole 2004). For $n > 2$, independent licensing in general makes welfare-decreasing pools only *weakly* unstable (that is, the competitive equilibrium is an equilibrium of the independent licensing game, but it may not be the only one). Boutin (2013) shows that strong instability of welfare-decreasing pools can be otained by appending the requirement that (in the symmetric case), the pool market individual licenses at the bundle price divided by the number of patents in the pool.[5]

[5]See also Rey-Tirole (2013) for a related insight on the effects of unbundling.

Coordinated effects create more opportunities for gaming the competitive process and require appending an extra instrument; indeed, independent licensing cum unbundling (the pool's price structure is super-additive and revenues are allocated according to licenses of individual patents through the pool) is a perfect screen (Rey-Tirole 2013). Interestingly, independent licensing is much less powerful in the context of a standard, as non-essential patents are made essential through the standardization process. Thus, further analysis is needed to understand patent pools in the context of standard setting.

This paper takes a Coasian view that gains from trade 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.

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

The 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. While the SSO has full flexibility in morphing, 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.[6]

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). The latter are heterogenous with respect to their opportunity cost θ of implementing the technology. A user with cost θ adopts the technology 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 θ is distributed on $\mathbb{R}^+$ according to density $f(\theta)$ and c.d.f. $F(\theta)$. The demand for the technology is

$$D(P(S) - V(S)) \equiv \Pr\left(\theta + P(S) \leq V(S)\right) = F(V(S) - P(S)).$$

We assume that F is twice continuously differentiable, for all S and $P \in (0, V(S))$ and has a monotone hazard rate ($(f/F)' < 0$ over the domain of definition); this assumption guarantees the log-concavity of profit functions as well as standard properties of reaction curves.

We do not assume that V is increasing in the number of functionalities (that is, that $V(T) \geq V(S)$ if $S \subset T$); for, a bulky 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 $V(S) > V(T)$. Conversely, letting

$$S^* \in \arg\max_S \{V(S)\},$$

a standard $S \subset S^*$ will be said to be *underinclusive*. For expositional simplicity, assume that $V(S^*) > V(S)$ for $S \neq S^*$.

Intellectual property and within-functionality competition index. The extent of competition to enable a functionality i is indexed by a maximum markup $m_i \geq 0$ 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 an intellectual property right while

[6] Alternatively, the 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.

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. The case $m_i \geq V(S)$ corresponds to a patent that 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.

For the sake of this paper, we will use this interpretation of a dominant patent holder on functionality i, or "patent holder i" for short. But oligopolistic interpretations are also admissible. There may be multiple patents reading on functionality i; their owners may be able to sustain a markup m_i because imperfect competition obtains in the submarket for functionality i.[7]

Finally, note that there is no real distinction between within-functionality and across-functionality substitution as long as the technology is fully malleable.[8] 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.

2.2 Competitive benchmark

2.2.1 Nash equilibrium in a putty technology world

Consider the "putty technology" thought experiment of a licensing market in which there are no network externalities. Because the model in particular considers general surplus functions, all results in this section are new.

The dominant IP owner in functionality i sets price $p_i \leq m_i$. For any price vector, let

[7] 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).

[8] 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',

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

$P(S)$ denote the total price of bundle S:

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

We now derive the competitive benchmark. We 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, 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. Under this requirement, the competitive prices necessarily sustain bundle S^*: Suppose that they sustain S; then $P(S^*) \leq P(S)$ and so $P(S^*) - V(S^*) < P(S) - V(S)$.

Definition 1 ***(Nash prices).*** *A vector of Nash prices $\{p_i\}_{i \in 1, \cdots, n}$ sustains S^* and is immune to the possibility of within-functionality and across-functionalities substitution; that is, for all i, $p_i \leq m_i$, and $V(S^*) - P(S^*) \geq \max\limits_{\{S|i \notin S\}} \{V(S) - P(S)\}$. It satisfies:*

(a) *for* $i \in S^*$

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

where

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

and

$$\widehat{p}_i \equiv \arg\max_{p}\ \{pD(p + P(S^* \backslash \{i\}) - V(S^*))\};$$

(b) $p_i = 0$ *if* $i \notin S^*$.

In words, Nash prices must respect the competitive constraint within the functionality ($p_i \leq m_i$), lead users to select the efficient bundle (and so $p_i = 0$ if $i \notin S^*$), and finally be such that within the efficient bundle, prices be set so as to maximize profits. When within-functionality substitution is strong (m_i is low):

$$p_i = m_i. \tag{1}$$

Provided that the within-functionality competitive constraint is not binding ($p_i < m_i$),

i's Nash price can take one of two forms. First, if the dominant IP owner on functionality $i \in S^*$ raises his price p_i, functionality i may be dropped from the users' "consumption basket":

$$V(S^*) - P(S^*) = \max_{\{S|i \notin S\}} \{V(S) - P(S)\}. \tag{2}$$

We will discuss shortly whether the parameter e_i measuring the essentiality of the functionality is uniquely defined 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). Condition (2) more generally implies that S^* is the optimal basket for users:[9]

$$V(S^*) - P(S^*) = \max_{S} \{V(S) - P(S)\}. \tag{2'}$$

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:[10]

$$p_i = \arg\max \ \{p_i D(p_i + P(S^* \backslash \{i\}) - V(S^*)\}. \tag{3}$$

Lemma 1 *Two unconstrained Nash prices must be equal: If $p_i = \widehat{p}_i$ and $p_j = \widehat{p}_j$, then*

[9] Suppose that users find that bundle $S \neq S^*$ offers a higher net value. Either $S^* \subset S$ and then $V(S^*) \geq V(S)$ and $P(S) \geq P(S^*)$ imply

$$V(S^*) - P(S^*) \geq V(S) - P(S),$$

a contradiction. Or there exists $i \in S^*$ such that $i \notin S$. But then condition (2) implies that

$$V(S^*) - P(S^*) \geq V(S) - P(S),$$

again a contradiction.

[10] Note that condition (3) posits that users keep buying S^* 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

$$V(S^*) - P'(S^*) < V(S) - P(S)$$

for some S such that $i \notin S$, where $P'(S^*) \equiv P(S^*) + p_i' - p_i$. 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

$$V(S^*) - P'(S^*) < V(S') - P'(S')$$

where $j \notin S'$, $i \in S'$ and $P'(S') \equiv P(S') + p_i' - p_i$. This however is inconsistent with $P'(S^*) - P(S^*) = P'(S') - P(S')$ and condition (2) for firm j.

$p_i = p_j$

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

$$r(P_{-k}) \equiv \underset{p_k}{\arg\max} \; \{p_k D(p_k + P_{-k} - V(S^*))\} \tag{4}$$

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 $p_i = p_j$. ■

Proposition 1 ***(existence)***. *There exists a Nash price vector.*

Proof. 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

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

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

and

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

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

2.2.2 Illustrations and uniqueness

Example 1: symmetric case. In the symmetric-patent case, all functionalities are interchangeable ($V(S)$ depends only on the number of selected functionalities) and $m_i = m$ for all i. Letting k^* denote the number of functionalities in S^*, a symmetric Nash per-patent price is given by

$$e = 0 \ \text{ if } \ k^* < n$$

and

$$V(S^*) - ne = \max_{k<n} \{V(S_k) - ke\} \ \ if \ \ k^* = n, \tag{5}$$

where S_k the set of the first k patents, or for that matter any subset of k patents (due to the symmetry); this latter case requires that $e \le \widehat{p}$, where $\widehat{p}$ is defined as in (3) for the symmetric case ($\widehat{p} = \arg\max \{pD((n-1)\widehat{p} + p - V(S^*))\}$). It can be shown that e is unique. The unique symmetric Nash price is thus given by $p = \min \{m, e, \widehat{p}\}$. Symmetry, however, does not guarantee uniqueness of Nash prices, as there may exist asymmetric equilibria.[11]

Proposition 2 ***(symmetric case)***. *There exists a unique symmetric Nash price, equal to* $\min \{m, e, \widehat{p}\}$*, where* e *is given by (5) and* $\widehat{p} \equiv \arg\max \{pD((n-1)\widehat{p} + p - V(S^*))\}$.

Example 2: uniquely-determined essentiality. Suppose that the essentiality parameters e_i are uniquely defined, i.e., independently of the prices charged by other patent holders. A trivial example is provided by $V(S) = \Sigma_{i \in S} e_i$. Another interesting class will be analyzed in Example 3. Equilibrium uniqueness is derived in a broader context, and indeed we will develop other applications of Proposition 3 later on.

Proposition 3 ***(unique equilibrium and comparative statics)***. *Suppose that for all* i*, firm* i *must select its price* p_i *only subject to the constraint* $p_i \le \widetilde{e}_i$ *for some known* $\widetilde{e}_i$*. Then*

(i) the Nash price vector is unique

(ii) if $\widetilde{e}_i' \le \widetilde{e}_i$ *for all* i*, then* $P^{c\prime}(S^*) \le P^c(S^*)$.

Proof. (i) Consider a set of Nash 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 Lemma 1, all prices in I_2 are equal to some $\widehat{p}$. Consider the function $r(\widehat{p})$ defined by:

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

[11] See Proposition 4 in Lerner-Tirole (2004).

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) 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. ■

For the purpose of this section, we take $\tilde{e}_i = \min\{m_i\ ,\ e_i\}$, which is uniquely defined if e_i is.

Example 3: concave surplus. Next, suppose that functionalities' incremental contributions to total value are decreasing: For any disjoint subsets S_1, S_2, S_3 (with S_2 and S_3 non empty),

$$V(S_1 \cup S_2 \cup S_3) + V(S_1) < V(S_1 \cup S_2) + V(S_1 \cup S_3) \tag{6}$$

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 (6) is satisfied.[12]

Proposition 4 ***(concave case).*** *Suppose that the surplus function exhibits decreasing incremental contributions (condition (6) is satisfied); and that $S^* = \{1, \cdots, n\}$. Then the*

[12] Take $S_1 = \emptyset$, $S_2 = \{1\}$, $S_3 = \{2\}$ in condition (6).

essentiality parameters are uniquely defined: for all i,

$$e_i = V(S^*) - V(S^* \backslash \{i\}). \tag{7}$$

The Nash price vector is therefore unique.

Proof. 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 $V(S^*) > \Sigma_{i \in S^*} e_i$. ■

Example 4: Decreasing incremental contributions is a sufficient, but not necessary condition for essentiality to be measured by the incremental contribution to the technology (condition (7)). Consider $n = 3$, with a symmetric value function $V(S) = \phi(\#S)$. Assume that $V(1) = V(0) = 0$, and $V(3) - V(2) = e$ where $3e \leq V(3)$. The technology is not concave and yet $e_i = e$ for all i.

2.2.3 Multiple Nash prices

The set of competitive prices need not be a singleton.

Example 5. 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 6. 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 $[V(S^*) - V,\, V(S^*)]$.

Discussion: 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 perform an exercise similar to that performed by Nash (1950) to select among equilibria. Namely there could be some small uncertainty in the value function ($V(S) + \varepsilon_s$) and one could let the noises converge to 0.[13] We leave this for future research.

Second, one can operate a 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.

2.2.4 Competitive benchmark in the putty technology world

We index by a superscript "c" a vector of competitive (Nash) prices and make an equilibrium selection if the Nash price is not unique (see Section 2.2.3). Let $P^m(S)$ denote the

[13] For example, suppose in Example 6 that $V(S^*) - V = \varepsilon$ where $\varepsilon \sim G(\cdot)$. Then, there is a strictly positive probability that the users' choice at the margin is between 2 and 3. Bertrand undercutting then yields $p_2 = p_3 = 0$ and so $p_1 = V(S^*) - V$.

monopoly price for an arbitrary bundle S:

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

We will repeatedly use the following lemma:

Lemma 2 *The lowest monopoly net price $P^m(S) - V(S)$ is obtained for $S = S^*$.*

Proof. The net monopoly price $\tilde{P}^m(S)$ for combination S solves

$$\max \; [\tilde{P} + V(S)]D(\tilde{P}),$$

and so, by revealed preference, is minimized for the highest $V(S)$. ∎

Note next that if there exists i such that p_i^c is determined by (3), then[14]

$$P^c(S^*) \geq P^m(S^*).$$

But even if no competitive price is determined by (3), the technology's price $P^c(S^*)$ may still exceed the monopoly price.

We are thus led to consider two cases, depending on whether the competitive price 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).[15] The hazard with pools is of course that they can be set up so as to raise price to the monopoly level in the other configuration. 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 package (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.

[14] By a revealed preference argument.

[15] Note also that condition (2) is a fortiori satisfied if the bundle S^* is sold at a lower price.

A "pool agreement" consists in a subset S of patent holders agreeing to market the bundle of their patents at some bundle[16] 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 sanguine, Coasian view of patent pool formation by assuming that gains from trade among IP owners are realized and so a pool forms if it is profitable (see Llanes-Poblete 2012 for a theoretical analysis of holdouts in patent pool formation). The following proposition extends Proposition 13 in Lerner-Tirole (2004).[17]

Proposition 5 ***(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 to actively grant individual licenses; furthermore, welfare is unique and the pool forms if either the Nash outcome is unique or, if there are multiple Nash outcomes, the equilibrium selection is consistent (a low net-price outcome is not selected just because a pool is set up).
(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.

Proof
(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 α_i's such that $\Sigma_{i\in S^*}\alpha_i \leq 1$.

Suppose that the pool with the functionalities in S^* is formed, with α_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

[16] Because users' payoff function is additive in $V(S)$ and (minus) θ, there is no extra profit to be gained from offering menus.
[17] As noted above, we add the distinction between functionalities and intellectual property, and we allow general surplus functions.

bundle from the pool. By definition of the Nash 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 Nash equilibrium prices, a contradiction if the Nash price is unique or the selection consistent.

To understand the need for a consistent selection in the case of multiple Nash prices, consider Example 6 in Section 2.2.3, and focus on the socially most efficient Nash 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.

(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 Nash 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 boost the demand for 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. ■

Discussion (guaranteeing strong instability of welfare-decreasing pools). 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 2013; see also Rey-Tirole (2013)'s results for the case of very impatient firms in a repeated game context). We here provide a different, but related result for the case of uniquely defined essentiality.

Suppose that the pool must offer a superadditive price structure: the pool must charge individual prices p_i^P so that the cheapest option to 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 from licenses are passed through by the pool to their owners. Assume finally that the essentiality parameters e_i are uniquely defined. The outcome is then *always the competitive outcome.* To see this, let

$$\tilde{e}_i' \equiv \min \{m_i, e_i, p_i^P\} \leq \tilde{e}_i \equiv \min \{m_i, e_i\}.$$

Proposition 3 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.

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

3 Standards: hold-ups, biased morphing and reverse hold-ups

Let us turn to the putty-clay environment of standards and first assume in Sections 3.1 through 3.3 that standard setting involves no price commitment at all. 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 a standard S. At that stage, cross-functionality substitutability is no longer an option. By contrast, within-functionality substitutability is still feasible for the implementers who deliver the final products to the end-users. Thus, the holder of the patent reading on functionality $i \in S$ sets p_i ex post so as to maximize profit,[18] and so

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

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

Proposition 6 ***(ex-post pricing).*** *Consider an arbitrary standard S and $i \in S$. 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^*:*
if $i \in I_1(S)$, $p_i^* = m_i \leq \widehat{p}$;
if $i \in I_2(S)$, $p_i^* = \widehat{p} < m_i$, where

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

Proof For a given $\widehat{p}$, let

$$P_{-i}(\widehat{p}) \equiv \sum_{\substack{j \in S \\ j \neq i}} \min \ \{m_i, \widehat{p}\},$$

a continuously weakly increasing function of $\widehat{p}$. The equilibrium condition, obtained from (3), is then $\widehat{p} = r(P_{-i}(\widehat{p}))$ where the reaction function r is a continuously decreasing function of P_{-i} and therefore a continuously weakly decreasing function of $\widehat{p}$. The fixed point is therefore unique.[19] ■

Proposition 6 offers a potential explanation for the puzzling fact that patents tend to be weighted equally in the sharing of royalties from pools. Observers have wondered about

[18] If $i \notin S$, then $p_i = 0$.
[19] Proposition 6 can be viewed as a special case of Proposition 3 with $e_i \equiv V(S^*)$ for all i.

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.

Proposition 7, which is strongly related to Proposition 3,[20] confirms the intuition that standard-essential patents command a high price:

Proposition 7 ***(total ex-post price exceeds total competitive price).*** *For all S,*

$$P^*(S) \geq P^c(S).$$

Proof See Appendix. ■

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.

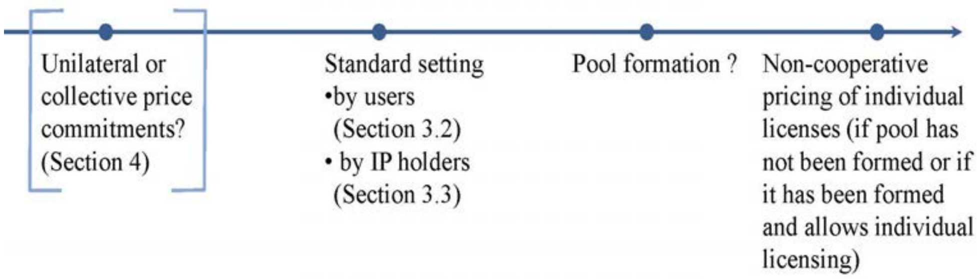

Figure 1: Timing in the absence of price discussions

Recall that patent holders are still constrained by within-functionality substitution, but cross-functionalities substitution is no longer feasible; thus, 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:

Proposition 8 ***(pools in the putty-clay framework)***
Under the provision that a pool cannot include multiple patents reading on the same func-

[20] Let $\tilde{e}'_i = m_i$ and $\tilde{e}_i = \min\{m_i,e_i\}$. Even if $\{e_i\}$ is not unique, it is still the case that $\min\{m_i,e_i\} \geq m_i$ for any selection of $\{e_i\}$.

tionality, an ex-post pool can only reduce total price even if members cannot individually license their patents.

Proof 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. ∎

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.

We make the following assumption, satisfied by standard bargaining solutions:

Assumption 1 ***(monotonicity in ex-post pool formation)***. *A pool can be formed after the standard is set. We assume that profit sharing depends only on, and is monotonic with respect to pre-pool formation profits: Patent holder i's share of the post-negotiation profit is non-decreasing in his share of the pre-negotiation profit.*

Allowing for the formation of a pool if the ex-post competitive price exceeds the monopoly price, let

$$P^*(S) \equiv \min\ \{\sum_{i \in S} \min\ \{m_i, \widehat{p}(S)\}, P^m(S)\} = \min\ \{\Sigma_{i \in S}\ m_i\ ,\ P^m(S)\} \tag{8}$$

3.2 Morphing by the users

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

$$\max_{\{S\}}\ \{V(S) - P^*(S)\}. \tag{9}$$

Will users choose the efficient technology S^* maximizing $V(\cdot)$, given that they have an eye on how much the technology will fetch ex post? Morphing by the users leads to two kinds of inefficiency:

(a) *Monopoly pricing.*

Ex-post price setting creates scope for opportunism by IP holders. Suppose that the within-functionality-competition constraint is not binding (say, $m_i \geq V(S^*)$) and so functionalities de facto coincide with patents.

Proposition 9 ***(ex post opportunism and choice of standard).*** *Suppose that functionalities de facto coincide with patents (m_i large for all i). When users select the standard and ex-post pricing prevail:*
(i) users select the efficient standard S^*;
(ii) the price of the technology is $P^m(S^*)$, and is therefore strictly higher than the competitive price whenever $P^c(S^*) < P^m(S^*)$.

Proof. 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, from Lemma 2, select $S = S^*$. ■

(b) *Essentiality-competition tradeoff*

In this framework, a functionality is characterized by two attributes: how essential the functionality is relative to the overall technology, and how intense is the 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 morphing biases, let us for the sake of the next two propositions 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 $\nu_5(S) = \infty$.

Definition 3 ***(essentiality ranking).*** *Functionalities $i = 1, \cdots, n$ are ranked in decreasing order of essentiality 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.[21] Furthermore S^* is generically unique. The following Proposition is proved in the Appendix:

Proposition 10 ***(inefficient morphing).*** *User choice of the standard*

(i) never results in overinclusive standards and may result in underinclusive ones;

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

3.3 Morphing 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 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 importance as in Definition 3, with functionality 1 the most important and so on.

[21] 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 $e_{k^*} > 0 \geq e_{k^*+1}$.

To analyze coalition formation, we define a *stability condition* similar to that in Levin-Tadelis (2005), who emphasize 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

$$\overline{k} \equiv \max \left\{ k \mid k = \arg\max_{\widetilde{k}} \max_{P} \left\{ \frac{PD(P - V(S_{\widetilde{k}}))}{\widetilde{k}} \right\} \right\}, \tag{10}$$

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 any 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 or SIG that will select $\overline{S}$.[22]

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

$$\max_{k} \max_{P} \{PD(P - V(S_k))\}.$$

Proposition 11 ***(malthusianism).*** *When the within-functionality-competition constraints do not bind, the patent holders covering the top $\overline{k}$ functionalities as given by (10) form a coalition. Furthermore, the standard is never overinclusive:*

$$\overline{k} \leq k^*.$$

Proof. 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 (10). ■

[22] "SIGs" are (largely captive) special interest groups that IP owners can use to obtain favorable standards (of course there is a trade off between leniency by the standard setter and credibility vis-à-vis the users). 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.

The malthusianism unveiled in Proposition 11 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 malthusianism; 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. Let us demonstrate that a similar result holds in our environment.

Suppose that demand for bundle S at price P is given by $F(V(S) - P + \gamma)$, where γ is a demand shifter and the hazard rate is monotone (f/F is decreasing). We have

Corollary 1 ***(shift in demand).*** *An increase in demand (i.e., an increase in γ) induces more malthusianism (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 – i.e., ones that incorporate non-willing participants IP – are doable. We have come across no discussions of such "guerilla standardization". The difficulties of doing so - the 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 Price discussions within the standard setting process: 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 engage in standard morphing. This approach creates scope for cartelization by implementers/users. Suppose that, in reduced form, the SSO's objective function is a convex combination of user surplus and IP owners' profit with relative weight $\alpha \leq 1$ for profits relative to user surplus:

$$\begin{aligned} W^{SSO}(S,P) &\equiv \int_0^{V(S)-P} [V(S) + (\alpha-1)P - \theta]\, dF(\theta) \\ &\leq \int_0^{V(S)-P} [V(S) - \theta]\, dF(\theta) \\ &\leq \int_0^{V(S)} [V(S) - \theta]\, dF(\theta) = W^{SSO}(S,0) \end{aligned}$$

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

Assume that the SSO 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).

Proposition 12 ***(reverse holdup)*** *Suppose that $\alpha \leq 1$. Then, under SSO bargaining power,*
(i) the SSO imposes $P(S) = 0$ for all S;
(ii) the SSO chooses the efficient standard ($S = S^*$).

Proof.
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, $\mathcal{P}(S) = [0, \Sigma_{i \in S} m_i]$. As we saw, $W^{SSO}(S,P) \leq W^{SSO}(S,0)$ for $\alpha \geq 1$. And so

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

Furthermore

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

is maximized for $S = S^*$. ■

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 blackmail 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.[23] Only when the SSO is very strongly biased in favor of IP owners will prices be non-expropriative.

Furthermore, IP owners may find it difficult to turn to an SSO that defends their interests (a high α SSO). Such 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 θ is user-idiosyncratic, and ξ is a common opportunity-cost-shifting or quality parameter that is assessed by the SSO). There is a tension between the two objectives of securing decent royalty rates and getting users on board. For, an SSO with a strong IP owner bias is likely to accept technologies of mediocre value to users (low ξ technologies).

4 Structured price commitments

4.1 Equilibrium under mandatory price commmitments

Under current practice, making individual or collective price commitments is difficult, regardless of one's willingness to do so. IP owners do not know at the start exactly which combinations of functionalities will work. Not only do individual IP owners not commit prior to standard setting to caps on their royalty rates; they also collectively do not form patent pools so as to directly influence the morphing of standards. Out of 23 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)

[23] 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 the final price.

pools. By contrast, the other, post-standard-setting pools were typical royalty-charging open pools.[24]

To give a better chance to price commitments, suppose that the standard setting process starts with a discovery phase, in which the various technology combinations are considered. It identifies the value propositions $V(S)$ for all S.[25] The SSO organizes a recess just before finalizing the standard. In this recess, firms commit to prices.[26] Then the final choice is made. Let us make this "structured price commitments" approach more formal. Following a value discovery phase,

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.

2. *Standard morphing*: The SSO is dominated by users. It is prohibited, as it currently is, from discussing prices: it only selects the standard.

3. *Ex-post pool formation*: The owners of patents that read on the selected standard

[24] 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. For instance, in September 2009, MPEG LA and the Japanese patent pool administrator announced a pool in which a variety of patents will be offered to companies based in Japan that sell mobile TV handsets for Japan's One-Seg mobile terrestrial broadcasting service. 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.

[25] In practice, it would identify the main feasible ones (to reduce the complexity – but keeping competitive threats of kicking out non-essential, but useful patents if their holders are too greedy).

[26] "Not committing" henceforth will refer to committing to a price cap, say $V(S^*)$, that would attract no demand for the licence.

can, if they wish so, form a pool (allowing independent licensing) 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.

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

We 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 Assumption 1 (monotonicity in the ex-post pool formation)

A corollary of monotonicity is the following observation:

Within-functionality substitution: A patent holder i whose functionality has been selected into the standard receives the same dividend from the pool whether he has committed to cap $\overline{p}_i > m_i$ or $\overline{p}_i = m_i$ at stage 1.

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 for that of p_i; it does not affect the pool value either. Thus it is natural to treat the choice of $\overline{p}_i$ in that range as irrelevant, as captured by the monotonicity requirement.

If out-of-pool, individual price commitments are made prior to pool formation, nothing guarantees a priori that patent holders will charge the Nash prices p_i^c, since their price commitments may affect:

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

(ii) *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;

(iii) *technology morphing* (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.

At stage 2, a user-friendly SSO chooses S so as to solve 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). Proposition 13 is a central result of the paper:

Proposition 13 ***(structured price commitments).*** *Under structured price commitments,*
(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. Futhermore, 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 outcome (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 to commit to ex-post prices $\bar{p}_i = p_i^*$ (given by Proposition 6).

Proof. (i) Assume that $P^c(S^*) < P^m(S^*)$ and suppose first that all patent holders commit to their competitive price $\bar{p}_j = p_j^c = \min \ \{m_j \ , \ e_j\}$, where the e_j are relative to the competitive price vector. Let 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 condition (2') 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 $\tilde{p}_i < \overline{p}_i = p_i^c = \min \ \{m_i \ , e_i\} \leq m_i$ and so necessarily

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

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 from Assumption 1 and the fact that the ex-post equilibrium prices are still the competitive prices, committing to cap $\overline{p}_i$ above m_i does not bring about any extra profit. Setting a cap below m_i is not profitable either: 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, recall that e_j is no longer relevant ex post and that $\widehat{p}_j = \arg\max \{p_j D(p_i + p_j + \Sigma_{k \in S^* \backslash \{i,j\}} p_k^c - V(S^*))\}$ is higher when p_i is lower. And so $\{p_j^c\}_{j \in S^* \backslash \{i\}}$ is still an ex-post equilibrium. Finally, note that at $p_i < p_i^c$, i's profit is increasing in p_i. So patent owner i only reduces profit by lowering price below m_i.

Or p_i^c is given by (2): $V(S^*) - P^c(S^*) = V(S) - P^c(S)$ for some S not including i. This means that users can guarantee themselves net value $V(S) - P^c(S)$ while if i raises ex post its price to $p_i > p_i^c$ (which i will do if $\overline{p}_i > p_i^c$), their ex-post utility is smaller than the level that would prevail if they chose S^* or any other standard including i. 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 $\{e_i\}$ are uniquely defined for all 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. 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 3) 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

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

and

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

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 3). Because $p_i = 0$ for $i \notin S$, then users can obtain net price for S^* at most equal to $P(S) - V(S^*) < P(S) - V(S)$. Hence $S = S^*$. And $P(S^*) \leq \Sigma_{i \in S^*}$ min $\{m_i\ e_i(S^*)\} = P^c(S^*)$.

(ii) Regardless of price commitments, the SSO can always pick standard S^*. From Proposition 3, in the absence of pool, the continuation game in individual license prices has a unique equilibrium. After, possibly, the formation of a pool,[27] the total price will not exceed $P^m(S^*)$. And so users can guarantee themselves net price $P^m(S^*) - V(S^*)$.

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

$$p^m < e < \min\{m, \hat{p}\}.$$

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 ε. 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 $P^m(2) - V(2)$, where $P^m(2) = \arg\max PD(P - V(2))$. If the SSO selects $S = \{2\}$ instead, the price will be $\min\{e, \tilde{p}^m\}$ where

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

and so the net price is higher for S than for S^*:

$$\tilde{p}^m - V(1) > P^m(2) - V(2).$$

Similarly,

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

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

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

[27] 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 $\Sigma_{\{m_i \le p\}} m_i + [\#\{i | p < m_i\}]p = P^m$. The unique equilibrium is then $p_i^{IL} = m_i$ if $m_i \le p$ and $p_i^{IL} = p$ (or $\ge p$) if $p < m_i$. Side transfers then take place, that depend on the respective bargaining powers.

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

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

and so from Assumption 1, 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 S^* is indeed 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, $\bar{p}_i > m_i$ or $\bar{p}_i > \hat{p}$ is not 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, where the last inequality derives from Proposition 7. 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 $P^m(S) - V(S) \geq P^m(S^*) - V(S^*)$. ■

Discussion (dispensing with FRAND?)

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 and FRAND are complements rather than substitutes. 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 Nash 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 Example 1 (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.[28] 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.

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. 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 $p_2^c = \min\ (m_2, e_2)$ (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 $p_1^c + p_2^c < \ddot{p}^m(S^*)$. Then price commitments reduce total profit.

[28] 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 Nash price.

Patent holder 2 is always hurt when price commitments are mandated.[29] 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

$$p_1^c D\left(p_1^c + p_2^c - V(S^*)\right) \leq \frac{P^m(S^*)}{2} D\left(P^m(S^*) - V(S^*)\right). \tag{11}$$

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 $\min(m_1, e_1)$ is) and the more essential the other patent (the higher $\min(m_2, e_2)$ is).

Proposition 14 ***(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;
(ii) in the asymmetric case and with $n = 2$, the owner of the less important patent prefers not having a price commitment; the owner of the most important patent prefers to avoid a price commitment if and only if $P^c(S^*) < P^m(S^*)$ and (11) holds.

Proposition 14 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, 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 (see Masoudi 2007 for an interesting view from the antitrust authorities' side and Lerner-Tirole 2013 for a further policy discussion).

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

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 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 any, 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.

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 morphing 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.[30]

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.

[30] 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.

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Appendix: Proof of Proposition 7

Proof. If $I_2(S)$ (as defined in the proof of Proposition 6) 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 6 that

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

where r_S denote the reaction curve corresponding to demand $P(S) \rightarrow D(P(S) - V(S))$ (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 $P^c(S) \leq P^*(S)$. ■

Appendix: Proof of Proposition 10

Either $P^*(S) = P^m(S)$; because $V(S^*) - P^m(S^*) \geq V(S) - P^m(S)$ for all S, S cannot be preferred to S^*. Or (from (8)) $P(S) = \Sigma_{k\in S}\ m_k$. 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 like in part (ii) 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 $P(S') = P(S) - (m_j - m_i) \leq P(S)$.
Proof. 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 ϕ is increasing and concave, c is the cost of including an extra functionality, $e_1 > e_2$, and

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

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

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

then users select $S = \{2\}$. ■

Appendix: Proof of Corollary 1

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 11 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 γ_k such that k is preferred to $k+1$ if and only if $\gamma \geq \gamma_k$. ■