EX-ANTE AGREEMENTS IN STANDARD SETTING AND PATENT POOL FORMATION

GASTÓN LLANES† AND JOAQUÍN POBLETE‡

Abstract. We present a model of standard setting and patent pool formation. We study the effects of alternative standard-setting and pool-formation rules on technology choice, prices and welfare. We find three main results. First, we show that allowing patent pools may reduce welfare when standards are negotiated and patent pools need to be ex-post incentive compatible. Second, we show that it is not possible to rank in welfare terms combinations of standard-setting and pool-formation rules when patent pools need to be ex-post incentive compatible. Third, we show that allowing firms to sign ex-ante agreements regarding pool participation dominates in terms of welfare any other policy rule. Our proposal does not require the Standard Setting Organization to have information on patent ownership, the terms of license agreements, or the value added of patents.

Keywords: Standard Setting, Patent Pools, Collective Ex-Ante Agreements, Coalition Formation (JEL: O31, O34, L15, L40).

1. Introduction

Standards are ubiquitous in modern life. Since its founding in 1947, the International Organization for Standardization (ISO) alone has published over 19,000 standards, offering technical specifications for products as diverse as cosmetics, gas turbines, semi-conductors and medical devices.

Technologies included in standards become essential for their implementation and may be covered by patents from several patent holders. Recent work in the economics and law literatures has raised concern that standardization may lead to royalty stacking (double marginalization) and high transaction costs. Patent pools are a potential solution to these problems, but only a handful of patent pools exist to date.

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† Pontificia Universidad Católica de Chile, gaston@llanes.com.ar.
‡ London School of Economics and Pontificia Universidad Católica de Chile, j.j.poblete-lavanchy@lse.ac.uk.

Most Standard Setting Organizations (SSOs) declare as their main objective to choose a standard with the best possible technical performance. For example, the European Telecommunications Standards Institute (ETSI) states that its objective is "to create standards and technical specifications that are based on solutions which best meet the technical objectives of the European telecommunications sector."

In practice, standards often require consensus between the SSO's members. For example, the Joint Electron Devices Engineering Council (JEDEC) is formed by manufacturers and suppliers of microelectronics, which participate in more than 50 technical committees and subcommittees, and decide standards through negotiation.

In any case, Standard Setting Organization (SSOs) do not explicitly encourage the creation of patent pools. Moreover, antitrust regulations forbid firms from discussing licensing agreements when setting standards, requiring patent pools to be ex-post incentive compatible, making more difficult their formation.

Clearly, the standard-setting and pool-formation processes are related: including the technologies of more firms in the standard affects the incentives to participate in the pool, and the prospect of pool formation affects firms' incentives to include more firms in the standard.

Considering the incentives to form patent pools when setting standards may have important implications. The extant literature has yet to address this issue, which is instead the main focus of this paper.

We present a framework for studying the standard-setting and pool-formation processes jointly. We study the effects of alternative standard-setting and pool-formation rules on technology choice, prices and welfare.

We model a standard as a set of technical components necessary for achieving compatibility when producing and selling a new product. A group of firms owns patents on technologies which may be used to implement these components. The standard simply specifies which technologies will be used for each component of the new product.

Our paper has three main results. First, we show that allowing patent pools may reduce welfare when standards are negotiated and patent pools need to be ex-post incentive compatible. Having more firms in the standard decreases pool stability. As a result, firms with high-value technologies may push for fewer firms in the standard, leading to the choice of a suboptimal technology.

Second, we show that it is not possible to rank in welfare terms combinations of standard-setting and pool-formation rules when patent pools need to be ex-post incentive compatible. Depending on the value of parameters, any policy rule may dominate in welfare terms the other rules. Thus, an SSO wanting to set policy rules in order to maximize welfare would need to have access to detailed information about the technology, patent ownership and transaction costs.

Third, we show that allowing firms to sign ex-ante agreements regarding pool participation dominates in terms of welfare all other policy rules. ex-ante agreements have two main effects: (i) firms can commit to be a part of the patent pool, which eliminates concerns about pool stability, and (ii) because firms negotiate before the standard is set, they agree on a division of surplus that compensates firms with high-value technologies for allowing firms with smaller marginal contributions to join the standard. As a result, the standard includes all firms with valuable technologies, which maximizes technical efficiency. Also, since the patent pool includes all firms, the efficiency losses from double marginalization and transaction costs are minimized.

In contrast with what happens in oligopoly settings with substitute products, the complementarity between technologies in a standard aligns the objectives of firms with those of customers. Having more firms in the standard and in the patent pool leads to higher industry profits and consumer surplus. By signing ex-ante agreements, firms can commit to be members of the pool and agree on an appropriate distribution of surplus.

The above analysis suggests that most of the inefficiencies associated with the existence of industry standards arise from the legal impossibility of firms to freely write contracts and compete to become a member in the standard before the standard is chosen. In other words we argue that the most efficient rule to alleviate the lack of competition after the standard formation is allowing firms to coordinate and compete to become standard members.

The patent pool problem is similar to the problem of a cooperative with equal sharing described by Spulber (2009). Hiring by the cooperative leads to low productivity because it is designed to maximize per capita profits. The problem of the cooperative can be solved if we allow for a market for cooperative membership to operate. In the same way, the patent pool formation process after the standard is chosen is unproductive because it maximizes member's profits. Allowing for unrestricted ex-ante agreements plays the same role as the market for membership in the cooperative problem.

1.1. **Literature review.** Our paper is a contribution to the standard-setting and patent-pool literatures.

The literature of standard setting studies the incentives to form standards, and the effects of public policies and standard setting rules on the characteristics and probability of success of the standards formed.

Lerner and Tirole (2006) present a model of forum shopping and show that firms will try to submit patents to SSOs that are favorable to them. Chiao, Lerner, and Tirole (2007) test this hypothesis empirically, and find there is a negative relationship between the extent to which an SSO is oriented to technology sponsors and the concession level required of sponsors, and a positive correlation between the sponsor friendliness of the selected SSO and the quality of the standard.

Dewatripont and Legros (2008) study the incentives to develop technologies which may be useful for a standard, and finds that when royalty payments are increasing in a firm's patent portfolio, firms may have incentives to "pad" by submitting non-essential patents to the SSO.

Simcoe (2012) presents a model in which firms search for ideas and have to agree on which idea will become the standard. The firm with the best idea offers a concession (payment) to the other firms to implement her idea as the standard, but firms may continue searching until they reach a consensus. Therefore, there may be a delay until an agreement is reached. Simcoe finds that sometimes, delays are efficient, since they allow the implementation of a higher-value technology. Then, he tests the model predictions using data from the Internet Engineering Task Force, and argues that the observed slowdown in standards production between 1993 and 2003 can be linked to distributional conflicts created by the rapid commercialization of the Internet.

Farrell and Simcoe (2012) study the rules for consensus standardization. Two firms propose solutions to form a standard, and the quality of the solutions is private information. The game ends when one player concedes, agreeing to the other player's proposal. They show there is a trade-off between screening and delay. Immediate random choice may outperform the war of attrition, or vice versa. They also find that policies that reduce players' vested interests, and hence delays, can strengthen the ex-ante incentive to improve proposals.

The literature on patent pools studies the welfare effects of cooperative pricing agreements, and the incentives to enter into such agreements by the holders of patents of a given technology standard.

The study of patent pools has its roots in the literature studying the complementary monopoly problem (Cournot, 1838; Sonnenschein, 1968; Bergstrom, 1978). If firms selling complementary goods choose a price for their products non-cooperatively, they disregard the cross-price effects, and therefore will set higher prices than those they would set if they were able to coordinate.

Shapiro (2001) was the first to propose the creation of patent pools to avoid the complementary monopoly problem caused by patent thickets. Lerner and Tirole (2004) generalized Shapiro's analysis for varying degrees of substitution between the extremes of perfect complements and perfect substitutes. An increase in the degree of substitution between the patented inventions reduces the market power of the patent holders, which leads to lower prices. If substitutability is high enough, cooperative price setting will lead to higher prices than uncoordinated price setting. Therefore patent pools are socially desirable only when they are composed of complementary patents.

Brenner (2009) uses Lerner and Tirole's (2004) framework to study optimal formation rules for patent pools, and finds that patent pools are welfare enhancing if compulsory individual licensing and exclusive pool membership are required.

Aoki and Nagaoka (2004) study the effects of the heterogeneity between upstream, downstream and integrated firms when pricing patents in a patent pool or outside a patent pool. The standard is given and there is no patent pool formation game. Instead, the focus is on downstream and upstream prices.

Lévêque and Ménière (2008) present a model of patent pool formation in which the existence of a standard is given. The authors compare the incentives to form a patent pool when the patent pool is formed before and after manufacturers commit to the standard, and find that allowing the formation of patent pools ex-ante facilitates the emergence of stable non-cooperative patent pools.

Choi (2010) uses Lerner and Tirole's (2004) framework to study the incentives to form patent pools or cross-licensing agreements when there is uncertainty about the validity and coverage of patents, and finds that pooling agreements may shelter invalid patents from challenges.

Notably, the extant literature has not studied the interactions between the incentives to form standards and the incentives to form patent pools. Our contribution is to present an integrated framework for studying both processes jointly. We show that the interactions between both processes have important implications on policy recommendations.

2. The model

We study the development of a standard determining the technical specifications of a new product to be introduced in the market.

Standardization requires defining the technical characteristics of three components of the product, a, b and c. There are alternative technologies that may be used for each component. A standard is simply an agreement over the technologies that will be used for each component of the new product.

Three firms hold patents on technologies which may be used to implement the components of the standard. Firm 1 owns patents on technologies for all three components. Firm 2 owns patents on a technology for component b only. Firm 3 owns patents on a technology for component c only. Figure 1 shows a diagram summarizing patent ownership in the industry.

	Component		
	a	b	c
Firm 1	X	X	X
Firm 2		X	
Firm 3			X

Figure 1. Patent ownership and available technologies by firm.

The value of the product for consumers depends on the technologies used for each component. Let v_{123} be the value of the product if the patents of firms 1, 2 and 3 are used. Let v_{12} be the value of the product if the patents of firms 1 and 2 are used, but not the patents of firm 3. Define v_{13} and v_1 in the same way. These are all the possible combinations that provide the necessary components for the product.

All firms have valuable patents, in the sense that the value of a standard is larger if the patents of a firm are included in it. For simplicity, we assume that

$v_{12} = v_{13}$. Then, the value of the standard depends only on the number of participants. Let n be the number of firms with patents on the standard, and let $v(n)$ be the value of a standard based on the technologies of n firms. Then, $v(3) = v_{123}$, $v(2) = v_{12} = v_{13}$, and $v(1) = v_1$.

A subset of the firms in a standard may form a patent pool. Firms in a patent pool delegate price-setting decisions to the pool administrator. Therefore, when patent pools are allowed, the number of price setters may be different from the number of firms with patents on the standard.

There is a continuum of users of the standard. The demand for the products based on the standard is $D(P) = v\,(1 - P)$, where P is the total acquisition cost for a buyer.

Let k be the number of price setters, and let r_i be the license fee chosen by price-setter i. License fees are per-unit royalties. Consumers have a cost c of transacting with each price-setter. The total acquisition cost for a buyer is the sum of license fees and transaction costs, $P = \sum_i r_i + k\,c$.

Technology choice and equilibrium prices depend on the rules governing the standard-setting and pool-formation processes.

Standard-setting rules establish how standard technologies are selected. There are two possibilities. Under a Technically-Efficient (T) rule, the standard maximizes technical efficiency. Under a Negotiated-Standards (N) rule, the standard results from negotiation by firms.

Pool-formation rules establish whether patent pools are allowed, and *when* they may be formed. There are three possibilities. Under an Uncoordinated-Pricing (U) rule, pools are not allowed. Under an Ex-Post Pool-Formation (EP) rule, firms are allowed to enter into pooling agreements, but only after a standard is chosen. Finally, under an Ex-Ante Pool-Formation (EA) rule, firms are allowed to sign agreements determining pool participation and the division of pool revenues before the standard is chosen.

The different possibilities for the standard-setting and pool-formation rules determine 5 cases, summarized in Figure 2.

In the Technically-Efficient Uncoordinated-Pricing case (TU), for example, the SSO chooses technologies to maximize the technical value of the standard and patent-pools are not allowed. In the Negotiated-Standards Ex-Post Pool-Formation case (NEP), firms form coalitions to propose standards, but may only form a patent-pool after the standard is set. In the Negotiated-Standards Ex-Post Pool-Formation case (NEA), firms form coalitions to propose standards, and may sign enforceable ex-ante agreements determining whether they will be part of a patent pool if their standard is chosen.

Note that under a Technically-Efficient rule, firms cannot influence technology choice. Therefore, the Ex-Post and Ex-Ante Pool-Formation rules yield the same results when a Technically-Efficient rule is in place, which is why we leave the intersection of Technically-Efficient and Ex-Ante Pool-Formation rules in Figure 2 empty.

Standard-Setting Rules

Pool-Formation Rules		Technically Efficient	Negotiated Standards
	Uncoordinated Pricing	TU	NU
	Ex-Post Pool Formation	TEP	NEP
	Ex-Ante Pool Formation		NEA

FIGURE 2. Standard-setting and pool-formation rules.

In what follows, we study the 5 cases from Figure 2. In Section 3, we study the effects of allowing patent-pools to form when standards are chosen to maximize technical efficiency. In Section 4, we study the effects of allowing patent-pools to form after the standard is chosen by a negotiation process by the firms. In Section 5, we compare the cases of Sections 3 and 4. Finally, in Section 6, we study the effect of allowing firms to sign agreements before the standard is chosen.

3. TECHNICALLY-EFFICIENT STANDARDS

In this section, we study the effects of allowing firms to form patent pools after the standard is chosen by the SSO to maximize technical efficiency. In other words, we compare TU and TEP from Figure 2.

Under TEP, firms may decide to form a patent pool. Firms in a pool delegate pricing decisions to the pool administrator, who sets a single price for the bundle of patents owned by firms in the pool. Therefore, if a pool is formed, the number of price setters will be smaller than the number of firms with claims on the standard. The pool maximizes joint profits and the proceeds are divided by bargaining according to Shapley Value.[1]

As is well known, there are two potential benefits from forming patent pools. First, patent pools alleviate the double marginalization problem (Shapiro, 2001; Lerner and Tirole, 2004; Llanes and Trento, 2012). Second, patent pools reduce transaction costs, by acting as intellectual property clearing-houses (Aoki and Schiff, 2010).

When the standard is chosen to maximize technical efficiency, firms cannot influence technology choice, in which case, the ex-ante and ex-post rules for patent pool formation are equivalent and pools need to be ex-post incentive compatible.

We define a pool to be incentive compatible if members of the pool cannot increase their profits by unilateral deviations. Given this simple model with three firms, this is equivalent to allowing for multi-lateral deviations. When both pools of size 2 and size 3 are incentive compatible according to our definition, we assume the largest pool will be formed. This can be shown to be the only Pareto optimal allocation of firms in pools.

The timing of the game is the following:

(1) The SSO chooses a standard.
(2) If allowed, firms decide whether to join a patent pool.
(3) Price-setters choose license fees.

We solve the game by backward induction. Let n be the number of firms with patent claims on the standard, and let t be the number of firms choosing to be members of the pool. Then, the number of price setters is $k = n - t + 1$.

The optimal price of price-setter i solves

$$\max_{r_i} \quad r_i \, v(n) \left(1 - \sum_i p_i - k\, c \right).$$

The symmetric-equilibrium price is

$$r(k) = \frac{1 - k\, c}{k + 1},$$

[1] The results are the same if the bargaining process is replaced by Nash Bargaining, the Kalai Smorodinski or the egalitarian Bargaining solution. For a comparison between these bargaining solution concepts, see Mas-Colell, Whinston, and Green (1995).

and the total acquisition cost for consumers is

$$P(k) = (1 + c)\,\frac{k}{k+1}.$$

Note that equilibrium price depends on the number of price setters, which may not coincide with the number of firms in the standard. Intuitively, the extent of double marginalization depends on the number of decision takers, which differs from the number of firms with claims on the standard in case a patent pool is formed.

Social welfare is

$$W(n,k) = v(n)\left(\frac{1}{2} + k\right)\left(\frac{1 - k\,c}{k+1}\right)^2.$$

The profit of a firm outside the pool is

$$\pi(n,k) = v(n)\left(\frac{1 - k\,c}{k+1}\right)^2.$$

After the standard is set, every firm in the standard becomes essential for its implementation. Since the added value of each firm is now equal to the total value created by the standard, according to Shapley value, the proceeds are divided equally among all firms in the pool, independently of the number of patents that each firm has. Thus, the profit of each firm in the pool is given by

$$\hat{\pi}(n,k) = \frac{1}{n-k+1}\,v(n)\left(\frac{1 - k\,c}{k+1}\right)^2,$$

A patent pool of size $t = n - k + 1$ is stable if and only if

$$\widehat{\pi}(n,k) \geq \pi(n,k+1).$$

Since the SSO chooses n to maximize the technical value of the standard, $n = 3$ in both TU and TEP. With TU, patent pools are not possible, so $k = n = 3$. With TEP, on the other hand, k is determined endogenously as a result of firms' decisions. Lemma 1 presents conditions for the formation of a patent pool in the TEP case.

Lemma 1. *If $n = 3$, there exist thresholds c_1, c_2, with $c_1 < c_2$, such that: (a) if $c < c_1$ no pool is formed, (b) if $c_1 \leq c < c_2$ a pool of two firms is formed, and (c) if $c \geq c_2$ a pool of size 3 is formed.*

The lemma shows that the likelihood and the size of the pools depends positively on transaction costs. The larger the transaction costs, the larger the benefits of forming pools, therefore the more likely and the larger pools are. An interesting corollary of this lemma is that welfare, profits and consumer surplus are non-monotonic on transaction costs. For example, increasing transaction costs from $c_2 - \varepsilon$ to $c_2 + \varepsilon$ will increase welfare if ε is small enough. The reason is that increasing transaction costs in this neighborhood makes it possible for firms to form a larger pool, reducing the double marginalization problem and the transaction costs effectively paid, thereby increasing consumer surplus, firm profits and welfare. In the last section, we show that a similar analysis can be conducted by changing consumer's price sensitivity.

Lemma 1 is also important because it allow us to compare the efficiency of the TU and TEP cases. We present the formal comparison in the next proposition. All proofs are in the Appendix.

Proposition 1. *If standards are chosen to maximize technical efficiency, allowing patent pools to form weakly improves welfare.*

Under a Technically-Efficient rule, all patents are included in the standard and become essential for its implementation (i.e., patents become perfect complements). In this case, a patent pool leads to higher welfare for two reasons. First, the patent pool lowers the number of price setters, thereby reducing the efficiency loss from double marginalization. Second, it lowers transaction costs by acting as an intellectual-property clearing house.

4. Negotiated standards with ex-post patent-pool formation

In this section, we study the effect of allowing firms to form patent pools after the standard is chosen through multilateral negotiation by all the potentially involved firms. We compare NU and NEP of Figure 2.

Firms form coalitions to propose a standard to the SSO, and the SSO chooses the standard that maximizes technical efficiency among such proposals. We require coalitions to be stable according to the following definition:

Definition 1. *A coalition is a set of firms with sufficient technologies for a standard. An allocation is a set of coalitions, such that their pairwise intersection is empty. An allocation A is said to block allocation A' if there is a coalition C in A, such that all firms in C are weakly better than under allocation A', and at least* *one of them is strictly better off. An allocation is stable if it does not exist another allocation blocking it.*

In this simple setting, it is easy to see that any coalition needs to include firm 1. Therefore, only one coalition can exist in any allocation. The only stable allocation is the one that contains the coalition that maximizes firm 1's profit. For simplicity, from now on, we will refer to the coalition in the stable allocation as the "stable coalition."

The timing of the game is the following:

(1) Firms form coalitions, and propose standards to the SSO.
(2) The SSO chooses a standard.
(3) If allowed, firms decide whether to join a patent pool.
(4) Price-setters choose license fees.

As in the previous section, after the standard is chosen, firms may decide to join a patent pool, dividing pool proceeds according to Shapley value. The main difference between this section and the previous one is that with negotiated standards, the prospect of patent pool formation may affect the incentives to include more firms in the standard.

The standard chosen in this collectivelly-negotiated process may not include all the firms in the industry, and therefore it may be technically inefficient. There are three reasons for this.

First, even though before the standard is chosen the marginal contribution of technologies owned by firms may be very different, after the standard is chosen all firms that own patents in the standard become essential and therefore are equally important. An *equalizing transformation* changes the nature of the relationship between patent owners before and after the standard is chosen. Firms that ex-ante have large incremental value will try to prevent firms with low incremental value to join the standard, because they will have to share the revenues equally with them due to the equalizing transformation.

Second, firms might try to include a suboptimal number of firms in order to reduce double marginalization and to reduce transaction costs. This may be beneficial from a private perspective, but socially inefficient.

Third, firms might want to have a small number of firms in the standard because they anticipate that it will be difficult to form a patent pool ex-post. In this case, by reducing the number of firms in the standard firms relax the incentive compatibility constraints necessary for patent pools to be stable.

For simplicity, in what follows we assume $v(1)$ is small, so that $n = 1$ is never an equilibrium. A sufficient condition is $v(1) < \frac{4}{9}\,v(2)$, which implies that $\pi(1,1) < \pi(2,2)$ for any c. As a result the resulting standard will have either three ($n = 3$) or two ($n = 2$) firms depending on parameters.

After the standard is chosen, firms need to decide wether they are willing to form a patent pool. It is easy to show that a patent pool is always formed if $n = 2$. Intuitively, it is always better to earn half of the monopolist rent than the rent of a duopolist. If $n = 3$ patent pools are formed according to Lemma 1.

The following proposition compares the efficiency of NU and NEP.

Proposition 2. *If standards are negotiated and patent pools must be ex-post incentive compatible, allowing patent pools to form may increase or decrease welfare.*

Proposition 2 shows that either NU or NEP may lead to larger welfare, depending on parameters values.

If NU and NEP lead to the same number of firms in the standard, NEP weakly dominates NU, because it allows the formation of patent pools, which lowers the welfare loss from double marginalization and transaction costs, just as in the case of Proposition 1. The welfare difference is even larger if NEP leads to a larger number of firms in the standard.

If NU leads to a larger number of firms in the standard, NU may welfare dominate NEP. The reason why NU may lead to a standard with more firms is that having fewer claimants increases *pool stability*. More firms in the standard imply better technology, which may outweigh the benefits of patent pools.

Proposition 2 is important because it shows that the prospect of patent pool formation can influence the standard-setting process, having a negative effect on social welfare. Intuitively, firms would prefer to form a patent pool after the standard is chosen. Without a credible commitment to participate in the pool, firms may choose standards that are technically inferior but involve fewer firms in order to achieve ex-post incentive compatibility.

5. Comparison

In this section, we compare the welfare implications of the different combinations of standard-setting and pool-formation rules in Sections 3 and 4. The main result of this section is that it is not possible to rank combinations of standard-setting and pool-formation rules without having information about the technology, patent ownership and transaction costs. An SSO that wants to set rules in order to maximize welfare will not only need to have access to all this information but also be incredibly sophisticated. The result is summarized in the next proposition.

Proposition 3. *The following rules for standard setting and patent-pool formation cannot be ranked in welfare terms:*

(1) *Technically-efficient standards with patent-pool formation (TEP).*
(2) *Negotiated standards with uncoordinated pricing (NU).*
(3) *Negotiated standards with ex-post incentive-compatible patent-pool formation (NEP).*

Proposition 3 follows from Proposition 2, from Section 4, and Lemmas 2 and 3, presented below. We discuss the economics behind the proposition by studying each lemma separately.

Lemma 2. *TEP and NEP cannot be ranked in welfare terms.*

Lemma 2 shows that there is a trade-off between technical efficiency and market efficiency when comparing NEP and TEP. On one hand, NEP leads to fewer firms in the standard and improves the incentives for patent pool formation, thereby reducing the welfare losses from double marginalization and transaction costs. On the other hand, TEP leads to the inclusion of all valuable patents in the standard, thereby maximizing technical efficiency. Depending on the relative strength of the two effects, either set of rules may lead to larger welfare.

Lemma 3. *NU and TEP cannot be ranked in welfare terms.*

Intuitively, if transaction costs are large, the temptation to remain outside a pool is small, and a technically-efficient rule where pools are allowed to form dominates a negotiated standard without pools.

If transaction costs are small, on the other hand, a negotiated standard may lead to a smaller number of firms, leading to a smaller welfare loss from double marginalization and transaction costs. Lemma 3 shows that if the loss from choosing a technically-suboptimal technology is small, negotiated standards lead to larger welfare that technically-efficient standards.

In sum, this section shows that it is difficult to choose policy rules if we consider the interaction between the standard-setting and pool-formation process.

This type of result is well known in the economics of regulation literature. Sometimes, regulating a market with distortions creates additional distortions. The main distortion that affects this market is the restriction preventing firms from signing contracts over the right to belong to the standard and the pool. Firms are only allowed to negotiate after the standard has been chosen, which affects their incentives to form standards.

Adding regulation on top of this distortion may lead to larger or smaller welfare, and only a highly-sophisticated and well-informed SSO could choose the optimal policy. In the next section, we present an alternative set of rules that requires no information from the SSO and improves welfare by allowing firms to sign ex-ante agreements.

6. Negotiated standards with ex-ante agreements

In this section, we allow firms to sign enforceable contracts establishing whether they will be members of the pool and specifying a distribution of surplus between firms in the pool. We compare NEA to all other policy rules in Figure 2.

A coalition in this case corresponds to a set of firms with enough technologies for a standard together with a sharing rule that divides the proceeds from the pool. The following definition explains the coalition-formation process in this case.

Definition 2. *An ea-coalition is a set of firms with sufficient technologies for a standard and a rule that determines how the proceeds from the pool are to be divided. An ea-allocation is a set of ea-coalitions, such that their pairwise intersection is empty. An ea-allocation A is said to block ea-allocation A' if there is an ea-coalition C in A, such that all firms in C are weakly better than under ea-allocation A', and at least one of them is strictly better off. An ea-allocation is stable if it does not exist another ea-allocation blocking it.*

Under NEA, revenue sharing is negotiated before the standard is chosen. At this stage, essential firms (firm 1) have a larger marginal contribution and therefore receive a larger share.

The fact that shares are not distributed equally among pool members is key in determining the efficiency of the pool. Because the share of marginal firms is smaller, essential firms are compensated for allowing firms with smaller marginal contribution in the standard, thus solving the equalizing transformation problem.

The proposition shows that with NEA, welfare is larger than with the policy combinations described in previous sections (TU, NU, TEP, NEP). Since this is the main result of the paper, we present its proof in the text.

Proposition 4. *A rule by which standards are negotiated and firms are allowed to sign enforceable ex-ante agreements regarding patent pool formation weakly dominates all other sets of rules in terms of welfare.*

Proof. We first show that any stable ea-coallition needs to be technically efficient. To the contrary, suppose that there is a technically inefficient ea-coalition $\widehat{C}$ of size $\widehat{n}$ that generates profits $\pi(\widehat{n}, 1)$ and the share of revenue for firm i in the ea-coalition is $\widehat{s}_i \cdot \pi(\widehat{n}, 1)$ with $\sum_{i=1}^{n} \widehat{s}_i = 1$.

Consider the technically efficient coalition C of size n that generates profits $\pi(n, 1) > \pi(\widehat{n}, 1)$ where share of revenue for each firm is given by the rule, if $i \in \widehat{C}$, the share is $\widehat{s}_i \cdot \pi(\widehat{n}, 1)$, if $i \notin \widehat{C}$, the share is $[\pi(n, 1) - \pi(\widehat{n}, 1)] / (n - \widehat{n})$. By construction, the sum of the shares equals the total revenues of the pool. The ea-coalition C blocks ea-coalition $\widehat{C}$ because all firms in C are not worse and firms included in C but not in $\widehat{C}$ are strictly better.

We now show that a technically-efficient stable ea-coallition always exists. Define D to be a technically efficient ea-coalition with the following sharing rule. Let the share of firm 1 (the essential firm) be $\Pi(n, 1)$, and let the share of all other firms be 0. Clearly, no coalition can block D because all coalitions need to include firm 1 and the share of firm 1 needs to be at least $\Pi(n, 1)$. Since $\Pi(n, 1) \geq \Pi(n', k)$ for any n', k it is not possible to make any firm strictly better off than under the ea-coalition D.

Finally, to show that any resulting ea-allocation weakly dominates any other possible standard achieved by any other rule, notice that in the model any stable ea-colation needs to be efficient and therefore has $n = 3$. It suffices to show that $W(3, 1) \geq W(n, k)$ for $n = 1, 2, 3$ and $k = 1, 2, 3$. This follows from noting that $W(n, k)$ is increasing in n and decreasing in k. ∎

The proof shows that with ex-ante agreements, technology choice is optimal and welfare losses from double marginalization and transaction costs are minimized.

To understand this result, note that TU, TEP, NU and NEP lead to inefficient outcomes for three reasons. NEA deals with these sources of inefficiencies in a non-conflicting way.

First, when a complete pool fails to be ex-post incentive compatible, double marginalization and transaction costs arise. This affects TU, TEP, NU and NEP. Ex-ante agreements deal with this problem because ex-ante pools are always incentive compatible.

Second, the equalizing transformation may lead to inefficiency because fewer firms are incorporated in the standard, leading to the choice of a suboptimal technology. This affects NU and NEP. NEA deals with this problem by allowing firms to negotiate profit sharing before the equalizing transformation takes place.

Third, concerns about future pool stability may also lead to fewer firms in the standard. This affects NEP. NEA deals with this problem by allowing firms to commit to participate in the pool.

The patent pool problem is similar to the problem of a cooperative with equal sharing described by Spulber (2009). Hiring by the cooperative leads to low productivity because it is designed to maximize per capita profits. The problem of the cooperative can be solved if we allow for a market for cooperative membership to operate. In the same way, the patent pool formation process after the standard is chosen is unproductive because it maximizes member's profits. Allowing for unrestricted ex-ante agreements plays the same role as the market for membership in the cooperative problem.

7. Discusion and extensions

The main result of the paper is that the best policy choice is to allow firms to negotiate standards and to sign pricing agreements before the standard is chosen.

Intuitively, in this setting with complementary goods and transaction costs, the interests of consumers and firms are aligned. Having more firms in the standard and in the pool leads to higher industry profits and consumer surplus. Firms can only achieve these objectives if they are allowed to have an active role in the decision on the technology standard and if they can internalize all externalities by signing contracts before the standard is chosen.

Our policy proposal has the advantage that it requires very little from the SSO. Firms will solve both problems efficiently by simply allowing them to sign enforceable pooling contracts before the standard is chosen, and to form coalitions to set the standard. The proposed solution reduces a complex problem to one where the only inefficiency left is monopoly pricing.

We also find that allowing firms to form pools after the standard is chosen may reduce welfare. After standards are chosen, an equalizing transformation decouples firms' marginal contribution from their bargaining positions. In anticipation to this transformation, firms with high-value technologies (i.e., large marginal contributions) have incentives to prevent the entry of firms with less valuable technologies to the standard. In addition, firms with high-value technologies may push for fewer firms in the standard in order to increase pool stability, leading to the choice of a suboptimal technology in a technical sense.

This result is an important contribution to the patent-pools literature, which emphasizes the benefits of patent pools when they are composed of complementary patents.

The model could be extended to include a parameter for price sensitivity. Price sensitivity affects our model in several ways. First, a larger price sensitivity worsens the effects of double marginalization. Second, a larger price sensitivity increases the importance of transaction costs, and increases the likelihood of patent pools. Third, a larger price sensitivity makes it relatively more important to achieve technical efficiency. To understand the third effect notice that a perfectly inelastic demand means that consumers are indifferent between any standard technologies.

To model these issues formally, we introduce a sensitivity parameter β into demands. The demand now is represented by $D(P) = v\,(1 - \beta P)$. In this case the price chosen by each price setter is given by

$$r(k) = \frac{1 - k\,\beta\,c}{k+1}.$$

As expected, the more sensitive the price is, the lower the individual prices chosen. The total acquisition cost for consumers is

$$P(k) = (1 + \beta c)\,\frac{k}{k+1}.$$

As can be seen from the equation above the effect of a larger price sensitivity is similar to the effect of a larger transaction cost. Comparative statics with respect to price sensitivity are equivalent to comparative statics with respect to transaction costs.

The model could also be extended to understand how different standard-setting and patent-pool rules affect incentives to innovate. Although a formal analysis of this problem is beyond the scope of this paper, it is worthwhile to point out that if collective ex-ante agreements are not allowed all patents in the standard obtain the same revenues (due to the equalizing transformation) and therefore there is no link between the firms' revenues and their marginal contribution to the technology. On the other hand, ex-ante agreements allow firms with larger marginal contributions to obtain a larger share of industry profits. Intuitively, this seems to suggest that choosing standards by using ex-ante agreements will induce innovators to do research in technologies with larger marginal contributions, which is likely to be desirable from a welfare perspective.

The analysis also shows that if standards are chosen by allowing for ex-ante agreements, the only distortion that prevents the market from achieving the first best is the monopoly pricing done by the pool. In a dynamic model where the market needs to provide firms with incentives to innovate, even these rents generated by the pool might be desirable from a welfare perspective.

Appendix: Proofs of propositions and lemmas in text

Proof of Lemma 1. A pool of size 3 will exist only if

$$\begin{aligned} \widehat{\pi}(3,1) &\geq \pi(3,2), \\ \frac{(1-c)^2}{4} &\geq \frac{(1-2c)^2}{3}. \end{aligned}$$

from which we obtain that $c > c_2$, where $c_2 \approx 0.118$. Recall that $c < 1/3$ throughout the paper. A pool of size 2 can exist only if

$$\begin{aligned} \widehat{\pi}(3,2) &\geq \pi(3,3), \\ \frac{(1-2c)^2}{9} &\geq \frac{(1-3c)^2}{8}. \end{aligned}$$

from which we obtain that $c > c_1$, where $c_1 \approx 0.051$. ∎

Proof of Proposition 1. The standard is chosen to maximize technical efficiency, which means that $n = 3$ under both TU and TEP. However, if a patent pool is formed, $k < n$ under TEP. By lemma 1, a pool will be formed if $c > c_1$. The result follows by noticing that $W(n,k)$ is decreasing in k for fixed n. ∎

Proof of Proposition 2. To prove the proposition it is enough to show that there are parameters under which NEP is preferred to NU and parameters under which the opposite happens.

To show that NEP can be preferred to NU consider the case of $c > c_2$ and $v(2) = 0$. In this case, the coalition will prefer to include all firms in the standard (otherwise the value is 0), and by the definition of c_2 a patent pool of size 3 will be formed. NEP is preferred to NU because under both schemes the standard includes all three firms but the former also implies a large patent pool avoiding double marginalization and transaction costs.

To show that NU can be preferred to NEP it suffices to find parameters such that the following conditions hold:

(1) When firms are not allowed to form a patent pool, they would rather belong to a standard of size three than to a standard of size two, $\pi(3,3) > \pi(2,2)$.
(2) Pools of size three are not stable, $\pi(3,1) < \widehat{\pi}(3,2)$.
(3) Firms would rather belong to a patent pool in a standard of size two than in a standard of size three with uncoordinated pricing, $\pi(2,1) > \pi(3,3)$.
(4) Welfare is larger with three uncoordinated firms than with a standard and patent pool of size two, $W(3,3) > W(2,1)$.

Condition 1 implies that under NU a technically efficient standard is chosen. Conditions 2 and 3 imply that under NEP, a standard and an associated patent pool of size 2 are formed. Condition 4 implies that a technically efficient standard with uncoordinated prices yields larger welfare than a standard of size 2 with a patent pool.

Substituting values, it is straightforward to check that all these inequalities are satisfied, for example, if $c = 0$ and $\frac{12}{7} < \frac{v(3)}{v(2)} < 2$. ∎

Proof of Lemma 2. Suppose that $c > c_2$. TEP implies $n = 3$ and $k = 3$ (every firm joins the patent pool), which means that it maximizes the technical value of the standard and minimizes the welfare loss due to double marginalization and transaction costs. If $v(3)/v(2)$ is small, NEP has $n = 2$, in which case TEP leads to larger welfare.

Suppose now that $c < c_1$. With TEP, $n = 3$ and no pool is formed. With NEP, a pool of 2 firms is formed if $n = 2$, and no pool is formed if $n = 3$. The stable coalition has $n = 2$ if and only if

$$\hat{\pi}(2,1) \geq \pi(3,3),$$

which is equivalent to

$$\frac{v(3)}{v(2)} \leq 2\left(\frac{1-c}{1-3\,c}\right)^2,$$

and welfare is larger with NEP if

$$W(2,1) > W(3,3),$$

which is equivalent to

$$\frac{v(3)}{v(2)} < \frac{12}{7}\left(\frac{1-c}{1-3\,c}\right)^2.$$

It is straightforward to show that the former condition is more restrictive than the later. Therefore, if $c < c_1$ and $\frac{v(3)}{v(2)} \leq 2\left(\frac{1-c}{1-3\,c}\right)^2$, NEP welfare dominates TEP. ∎

Proof of Lemma 3. Suppose that $c > c_2$. Then, TEP leads to $n = 3$ and a complete pool. With NU, on the other hand, there is no pool and n may be equal to 2. Therefore, if $c > c_2$, TEP welfare dominates NU.

Suppose now that $c < c_1$, which means that there is no patent pool with TEP, and that $v(3)$ is close to $v(2)$. In this case, NU will have $n = 2$, and will lead to a smaller loss from double marginalization. Since the technological gain from having $n = 3$ is very small, NU welfare dominates TEP. ∎

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