EX-ANTE AGREEMENTS IN STANDARD SETTING AND PATENT-POOL FORMATION*

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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. This policy 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, Royalty Stacking, Ex-Ante Agreements, Coalition Formation (JEL: O31, O34, L15, L40).

1. Introduction

Standard Setting Organizations (SSOs) play a key role in the development of technical standards.[1] Most SSOs declare that their main objective is to choose standards with the highest 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."

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[1] The International Organization for Standardization (ISO) alone has published over 19,000 standards since 1947, offering technical specifications for products as diverse as cosmetics, gas turbines, semi-conductors and medical devices. Other SSOs, such as the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU), are equally active.

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

The technical characteristics and performance of the standard will depend on whether component technologies are selected to maximize technical efficiency or decided through negotiation. SSO's members may be more interested in maximizing profits than in maximizing the technical performance of the standard, which may lead to the election of a technically suboptimal standard. The conflict between technical efficiency and profit maximization has sparked a thriving literature studying how standard-setting rules affect technology choice and the adoption of the standard (Lerner and Tirole, 2006; Chiao, Lerner, and Tirole, 2007; Dewatripont and Legros, 2008; Simcoe, 2012; Farrell and Simcoe, 2012; Layne-Farrar, Llobet, and Padilla, 2013; Kyle and Salant, 2013; Schmidt, 2013).

Adoption depends not only on technical performance, but on the cost of adoption for users. Recent papers show that standardization may lead to royalty stacking (Shapiro, 2001; Lerner and Tirole, 2004; Llanes and Trento, 2012) and high transaction costs (Aoki and Schiff, 2010), in which case the adoption of technologies by users may be suboptimal.[2] Patent pools are a potential solution to these problems, but only a handful of patent pools exist to date.

The main reason why patent pools fail to form is that they are generally not incentive compatible (Bloch, 2005; Brenner, 2009; Choi, 2010). Even though industry profits are maximized if all firms join the pool, the individual profits of a patent holder may be larger if she stays out of the pool.

SSOs do not explicitly encourage the creation of patent pools (CITATION), and antitrust regulations forbid firms from discussing licensing agreements when setting standards (CITATION). Given that patent pools are ex-post desirable, should SSOs encourage the formation of patent pools? Should antitrust authorities allow pricing agreements at the standard-setting stage?

The above discussion shows that it is important to study the interactions between the standard-setting and pool-formation processes. Furthermore, standards

[2]The study of royalty stacking has its roots in the literature studying the complementary monopoly problem (Cournot, 1838; Sonnenschein, 1968; Bergstrom, 1978). Royalty stacking is also related with double marginalization, but some authors prefer to reserve the latter term for the study of vertical relations between upstream and downstream firms.

and pools are related in a more fundamental dimension: including the technologies of more firms in the standard affects firm's incentives to participate in the pool, and the prospect of pool formation affects firms' incentives to include more firms in the standard.

We present a model of standard setting and patent-pool formation to address the following questions: (i) How do standard-setting and pool-formation rules affect technology choice and prices? (ii) Is it possible to design a set of rules that allows SSOs to achieve technical efficiency, while minimizing the efficiency losses from royalty stacking and transaction costs? and (iii) What are the informational requirements of such a policy? The extant literature has not addressed these issues in an integrated framework, which is the focus of our paper.[3]

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 to implement each component of the 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

[3]A notable exception is the paper by Lévêque and Ménière (2011), which studies the incentives to form a patent pool if the patent pool is formed before or after manufacturers commit to a standard, and shows that allowing the formation of patent pools ex-ante facilitates the emergence of stable non-cooperative patent pools. However, the standard is given, so this paper does not study the effects of patent pool formation on the choice of the standard.

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 royalty stacking 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.

Our results are also related with Coase's theorem on property rights (Coase, 1960). According to Coase, if participants can trade on all externalities from an activity, no matter who has property rights the outcome turns out to be efficient. In this paper we show that it is sufficient to allow firms that participate on a standard to contract among themselves on the externalities they have with each other. However, the result is not obvious from Coase's theorem because in our model we do not allow firms to trade on the externalities affecting customers or on the externalities affecting firms that are left outside of the resulting standard.

2. The model

2.1. **Technology and demand.** We study the development of a standard by a Standard-Setting Organization (SSO). The standard specifies the technical characteristics of a new product. The product has M components, and alternative patented technologies may implement each component. A standard is simply an agreement over the technologies that will be used to implement each component of the product. Users wanting to comply with the standard must employ the selected technologies. Thus, although there may be alternative ways to implement a component before choosing the standard, technologies become essential once they are included in the standard.

The SSO is composed by N firms with patents on standard-related technologies. In the next section, we describe how the SSO chooses the standard's technologies. Firms want the SSO to include their technologies in the standard, but are also concerned about the standard's value, which depends on the technologies of other firms. Let $v(n)$ be the maximum value of a standard based on the patents of n firms. By definition $v(n)$ is weakly increasing in n. We assume all firms have at least one desirable patent, which means that $v(n)$ is strictly increasing in n, and that $M \geq N$.

We assume firm 1 owns patents on technologies for all components, and also owns patents on the only technology implementing one of the components. Therefore, firm 1 is the only firm that is necessary and sufficient to implement the standard. The model can be easily generalized to have a subset of firms that are jointly necessary and sufficient.

Adoption of the standard depends on its technical performance and on the acquisition cost for users. Users have to pay license fees to firms with patents in the standard, but also have to incur in a transaction cost to negotiate each licensing agreement.

If antitrust authorities allow pooling agreements, firms with patents covering the standard may form a patent pool. Firms in the patent pool delegate price-setting decisions to the pool administrator. Let k be the number of price setters and t be the number of firms in the patent pool. In the absence of a patent pool, each firm is a price setter, so $k = n$. If a patent pool of size $t > 1$ forms, the number of price setters is $k = n - t + 1$, which is smaller than the number of firms with patents in the standard.

Demand for the product based on the standard is $D(P) = v\,(1 - P)$, where P is the total acquisition cost for a buyer. Let r_i be the license fee of price-setter i. License fees are per-unit royalties, and 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, $P = \sum_i r_i + k\,c$. To ensure demand is non-negative, we assume $c\,N < 1$.

We will use the following example with three firms and three components to illustrate the main results of the paper.

Example 1. The product has three components: a, b, c. Three firms hold patents on the technologies that may implement those components ($M = N = 3$). 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 summarizes patent ownership in this example.

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

FIGURE 1. Patent ownership and available technologies in Example 1.

If the standard is based on firm 1's patents alone, its value is $v(1)$. Firm 2, however, owns patents on valuable technologies for component b. Likewise, firm 3 owns patents on valuable technologies for component c. Suppose firm 2's patents are more valuable than firm 3's patents when used in conjunction with firm 1's patents. Thus, adding the patents of firm 2 to the standard would increase the standard's value to $v(2)$. If the standard uses the technologies of all firms, its value is $v(3)$. The fact that all firms have valuable patents implies that $v(3) > v(2) > v(1)$, as we assume in our general model.

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

Standard-setting rules establish how the SSO chooses the standard. There are two possibilities. Under a Technically-Efficient rule (T), the SSO chooses the standard to maximize technical efficiency. Under a Negotiated-Standards rule (N), the standard results from negotiation by firms in the SSO. We describe the negotiation process in detail in Section 4.

As we discussed in the introduction, most SSOs declare that their objective is to maximize technical efficiency, but SSOs are formed by firms with patents on standard-related technologies, which may be interested in maximizing their profits rather than technological performance. Thus, it is important to study the different implications of the two standard-setting rules.

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

The different possibilities for the standard-setting and pool-formation rules yield 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 firms cannot form a patent-pool. In the Negotiated-Standards Ex-Post Pool-Formation case (NEP), firms negotiate which technologies will be part of the standard, but may only form a patent-pool after the standard is set. In the Negotiated-Standards Ex-Ante Pool-Formation case (NEA), firms negotiate the standard and may sign enforceable ex-ante agreements determining whether they will be part of a patent pool.

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. For this reason, we leave the intersection of Technically-Efficient and Ex-Ante Pool-Formation rules in Figure 2 empty.

In what follows, we study the 5 cases from Figure 2. In Section 3, we study the effects of allowing patent-pools when standards maximize technical efficiency. In Section 4, we study the effects of allowing patent-pools after the negotiation process determines the standard. In Section 5, we compare the cases of Sections

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.

3 and 4. Finally, in Section 6, we study the effect of allowing firms to sign ex-ante agreements.

3. Technically-efficient standards

In this section, we study the effects of allowing firms to form patent pools after the SSO chooses the standard to maximize technical efficiency. In other words, we compare TU and TEP of 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, in order to maximize joint profits. Since the added value of each firm is now equal to the total value created by the standard, the proceeds are divided equally among all firms in the pool, independently of the number of patents of each firm. Equal sharing is consistent with most bargaining solutions, such as the Shapley value or Nash bargaining, given that in this case all players have the same added value.

There are two potential benefits from forming patent pools. First, patent pools alleviate the royalty stacking 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 SSO chooses the standard 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.

We define a pool to be incentive compatible if members of the pool cannot increase their profits by unilateral deviations. When both pools of size t and size

$t+1$ are incentive compatible according to our definition, we assume the largest pool will be formed. This equilibrium can be shown to be the only Pareto optimal allocation of firms in pools. For simplicity, we only allow for at most one pool to exist.

The timing of the game is the following. First, the SSO chooses a standard. Second, if pools are allowed, firms decide whether to join a patent pool. Third, price-setters choose license fees.

We solve the game by backward induction. The optimal license fee of price-setter i solves

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

The symmetric-equilibrium price is

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

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. Intuitively, the extent of royalty stacking depends on the number of decision takers, which may be different from the number of patent-holders if firms can form patent pools.

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

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

Because of equal sharing, the profit of a firm inside the pool is

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

Finally, 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 the number of firms in the standard to maximize the technical value of the standard, $n = N$ in both TU and TEP. With TU, patent pools are not possible, so $k = n = N$. 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 for given $n > 2$. All proofs are in the Appendix.

Lemma 1. *For given $n > 2$, the size of the pool is weakly increasing in transaction costs c. A pool does not form for c close to 0. A pool always forms for c close to $1/N$.*

Lemma 1 shows that the likelihood and the size of the pools depends positively on transaction costs, for given n. 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 Lemma 1 is that welfare, profits and consumer surplus are non-monotonic on transaction costs. Lemma 1 implies that there are thresholds c_t such that a pool of size t is formed for $c = c_t - \varepsilon$ and a pool of size $t + 1$ is formed for $c = c_t + \varepsilon$. Thus, increasing transaction costs in the neighborhood of c_t makes it possible for firms to form a larger pool, thereby reducing the royalty stacking problem and the transaction costs effectively paid, and 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.

In Example 1, the technically efficient standard has $n = 3$. Given $n = 3$, there are two thresholds for transaction costs, $c_1 = 0.05$ and $c_2 = 0.12$, which determine the equilibrium size of the pool. If $c < c_1$ there is no pool. If $c_1 < c < c_2$ there is a pool of size 2. If $c > c_2$ there is a pool of size 3. Figure 3 shows welfare (W) and total industry profits (Π) as a function of transaction costs for $v(3)/v(2) = 2$. As expected, welfare and industry profits are non-monotonic on transaction costs.

Lemma 1 allows us to compare the efficiency of TU and TEP. We present the formal comparison in the next proposition.

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 royalty stacking. Second, it lowers transaction costs by acting as an intellectual-property clearing house.

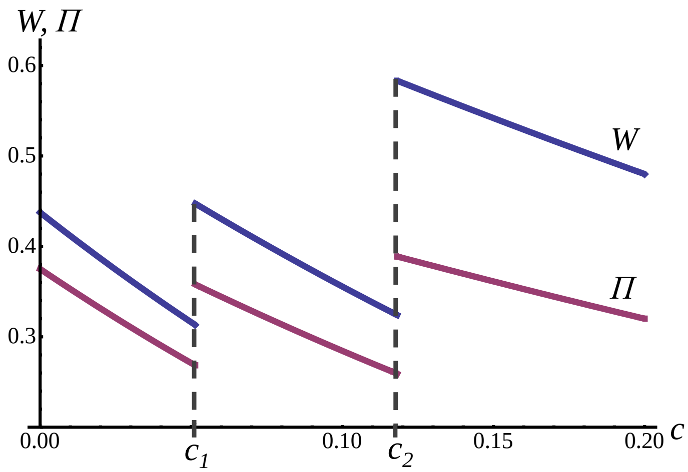

FIGURE 3. Welfare and total industry profits with $n = 3$

4. NEGOTIATED STANDARDS WITH EX-POST PATENT-POOL FORMATION

In this section, we study the effect of allowing firms to form patent pools after a multilateral negotiation to define the standard takes place among all potentially involved firms. In other words, we compare NU and NEP of Figure 2.

We model the negotiation process as follows. 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. First, firms form coalitions and propose standards to the SSO. Second, the SSO chooses a standard. Third, if pools are allowed, firms decide whether to join a patent pool. Finally, price-setters choose license fees.

As in the previous section, after the standard is determined, firms may decide to join a patent pool, dividing pool proceeds according to Shapley value. 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 $n > 2$ patent pools are formed according to Lemma 1.

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. Thus, the standard may not include all firms with valuable patents, leading to a technically-inefficient technology. There are three reasons for this result.

First, even though before the standard is set the marginal contribution of technologies owned by firms may be very different, after the standard is set 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 defined. Thus, firms that ex-ante have large incremental value will try to prevent that firms with low incremental join the standard, because they will have to share revenues equally with them due to the equalizing transformation.

Second, firms may try to include a suboptimal number of firms in order to reduce their loss from royalty stacking and transaction costs.

Third, firms may 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. Reducing the number of firms in the standard firms relaxes the incentive compatibility constraints necessary for patent pools to be stable.

The following proposition compares the efficiency of NU and NEP, and shows that either NU or NEP may lead to larger welfare, depending on parameters values.

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.*

If NU and NEP lead to the same number of firms in the standard, NEP weakly dominates NU. The reason is that NEP allows the formation of patent pools, which lowers the welfare loss from royalty stacking 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.

NU may welfare dominate NEP if it leads to a larger number of firms in the standard. The reason why NU may lead to a standard with more firms is that having fewer claimants increases *pool stability*. Having more firms in the standard leads to a better technology, which may outweigh the benefits of patent pools if the incremental value of having more technologies is large enough.

Figure 4 shows regions of parameters for which NU or NEP lead to higher welfare in the case of Example 1. In the figure, $X \succ Y$ indicates that X leads to higher welfare than Y, and $X \sim Y$ indicates that X and Y lead to the same welfare.

As expected, NU may lead to higher welfare than NEP for low values of c ($c < c_1$) and intermediate values of $v(3)/v(2)$. If transaction costs are small, NEP does not lead to a complete pool when $n = 3$. If $v(3)/v(2)$ is small enough, firms choose $n = 2$ in order to achieve pool stability. Under NU, if $v(3)/v(2)$ is large enough, firms choose $n = 3$ because they are not concerned with pool stability. Therefore, for intermediate values of $v(3)/v(2)$, NEP leads to $n = 2$ and a patent pool of 2 firms, and NU leads to $n = 3$ with no patent pool. If parameters are such that the technological gain from having a better standard is larger than the efficiency gain from having a patent pool, NU will lead to higher welfare than NEP.

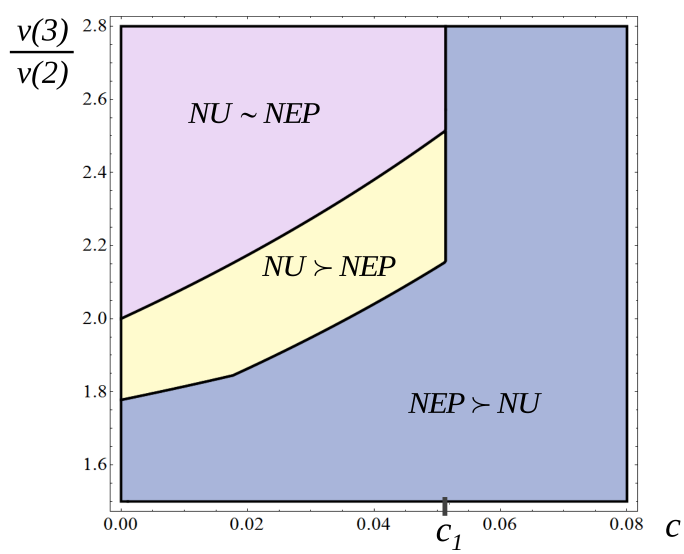

FIGURE 4. Welfare comparison between NU and NEP.

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, 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: (i) Technically-Efficient Standards with Ex-Post Patent-Pool Formation (TEP), (ii) Negotiated Standards with Uncoordinated Pricing (NU), and (iii) Negotiated Standards with Ex-Post 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.*

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 its technical efficiency. Depending on the relative strength of the two effects, either set of rules may lead to larger welfare.

Figure 5 shows regions of parameters for which TEP or NEP lead to higher welfare in the case of Example 1. Note that the area of TEP $\succ$ NEP (light-colored

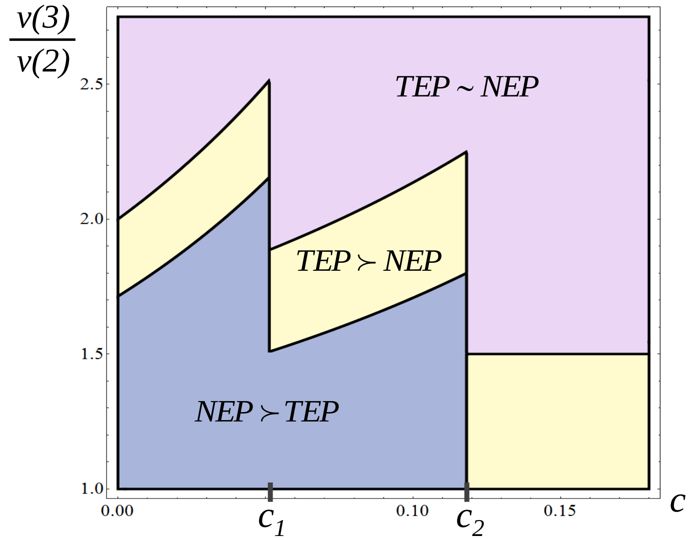

FIGURE 5. Welfare comparison between TEP and NEP.

area) is composed of three disjoint areas. According to Figure 5, if transaction costs are low ($c < c_1$), NEP dominates TEP for low $v(3)/v(2)$ and TEP dominates NEP for intermediate $v(3)/v(2)$. If transaction costs are low, no pool will form with $n = 3$ under both NEP and TEP. Under NEP, if $v(3)/v(2)$ is low enough, firms in the SSO will choose $n = 2$ in order to have a pool ex-post. For small $v(3)/v(2)$, the efficiency gain from having a patent pool is larger than the technological gain from having a better standard, and NEP leads to higher welfare than TEP. For intermediate $v(3)/v(2)$, technological efficiency is more important and TEP provides higher welfare.

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

The logic behind Lemma 3 is the following. 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, a negotiated standard may lead to a smaller number of firms, and reduce the welfare loss from royalty stacking and transaction costs. If the loss from choosing a technically-suboptimal technology is small, a negotiated standard will lead to larger welfare that a technically-efficient standard.

What about the equalizing transformation?

Figure 6 shows regions of parameters for which NU or TEP lead to higher welfare in the case of Example 1. According to Figure 6, NU dominates TEP only

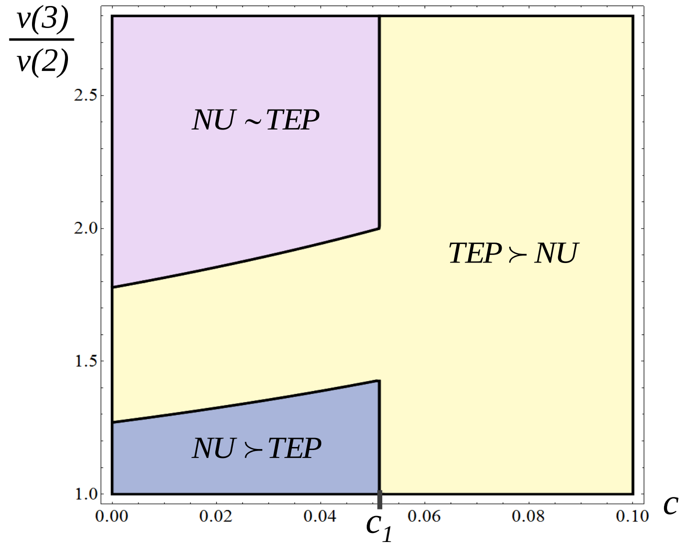

FIGURE 6. Welfare comparison between NU and TEP.

for low transaction costs ($c < c_1$) and $v(3)/v(2)$. If transaction costs are low, no pool will be formed under TEP. Under NU, firms in the SSO will choose $n = 2$ to avoid royalty stacking, transaction costs and the equalizing transformation. If the efficiency gain from lowering royalty stacking and transaction costs is larger than the technological gain from having a better standard, NU will lead to higher welfare than TEP.

In sum, this section shows that it is difficult to choose an optimal policy rule if we take into account the interaction between the standard-setting and pool-formation processes. This type of result is well known in the literature of the economics of regulation: regulating a market with distortions may create 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 determined, 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 would be able to 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 unequivocally.

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 determining the distribution of surplus between firms in the pool. In other words, 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.

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, firms negotiate revenue sharing before the standard is determined. At this stage, essential firms (in our case, 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 letting firms with a smaller marginal contribution join 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. We prove this result by contradiction. Suppose 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 $\left[\pi(n,1) - \pi(\widehat{n},1)\right]/(n-\widehat{n})$. 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 $n = N$. It suffices to show that $W(N,1) \geq W(n,k)$ for all n, k. This follows from noting that $W(n,k)$ is increasing in n and decreasing in k. ∎

The proof shows that ex-ante agreements lead to an optimal technology choice and minimize the losses from royalty stacking and transaction costs.

To understand this result, note that TU, TEP, NU and NEP lead to inefficient outcomes for three reasons.

First, when a complete pool ($t = n$) fails to be ex-post incentive compatible, royalty stacking and transaction costs arise. This problem 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 firms have incentives to include fewer firms in the standard. This problem affects NU and NEP. Ex-ante agreements deal 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 problem affects NEP. Ex-ante agreements deal 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 create a market for cooperative membership. In the same way, having the pool-formation process after the standard is defined is unproductive because equal sharing implies that the pool administrator maximizes per-capita profits. Allowing for unrestricted ex-ante agreements plays the same role as the market for membership in the cooperative problem.

7. Discussion and extensions

The main result of the paper is that the best policy choice is to allow firms to negotiate standards and to sign price 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 determined.

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 patent pools after the standard is negotiated may reduce welfare. After the standard is defined, 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 magnifies the welfare loss due to royalty stacking. Second, a larger price sensitivity increases the importance of transaction costs and 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. Demand is $D(P) = v\,(1 - \beta P)$, which leads to the following equilibrium price:

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

As expected, the more sensitive demand 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 equivalent to the effect of a larger transaction cost. Thus, 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 the 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. This result 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 with ex-ante agreements, the only distortion that prevents the market from achieving the first best is monopoly pricing 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 may be desirable from a welfare perspective.

Finally, we are assuming that the technologies of firm 1 are essential, which means there can be only one standard in the market. Allowing for competing standards is beyond the scope of this paper, but is an interesting direction for further research.

Appendix: Proofs of Propositions and Lemmas in text

Proof of Lemma 1. To prove the first part of the lemma it suffices to show that if a pool of size t is stable for some c, then it is also stable for all $c' > c$.

A pool of size $t \leq n$ will exist only if

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

where $k = n - t + 1$. This inequality can be rewritten as

$$\begin{aligned} \frac{1}{n-k+1}\, v(n) \left(\frac{1-k\,c}{k+1}\right)^2 &\geq v(n) \left(\frac{1-k\,c-c}{k+2}\right)^2, \\ \frac{1}{\sqrt{(n-k+1)}} \frac{k+2}{(k+1)} &\geq 1 - \frac{c}{1-kc}. \end{aligned}$$

Our assumption that $Nc < 1$ implies that $kc < 1$. The expression in the right hand side is therefore decreasing in c, which means that if the condition holds for some c, it also holds for all $c' > c$.

To show that with $n > 2$ a pool does not exist when $c = 0$, suppose it does. With $c = 0$ the condition for a pool of size t to exist is

$$\begin{aligned} \frac{1}{n-k+1}\, v(n) \left(\frac{1}{k+1}\right)^2 &\geq v(n) \left(\frac{1}{k+2}\right)^2, \\ \left(\frac{k+2}{k+1}\right)^2 + k &\geq n+1, \end{aligned}$$

The term on the left hand side is increasing in k for $k \geq 1$, therefore a necessary condition for a pool to exist, is that a pool with the largest number of price setters exist. Replacing k for $n-1$, we obtain

$$\left(\frac{n+1}{n}\right)^2 \geq 2,$$

which does not hold for $n > 2$.

To show that if c is close to $\frac{1}{N}$ a pool always exist, suppose it does not. Then, it must be the case that for any $k < N$:

$$\frac{1}{N-k+1}\, v(N) \left(\frac{1-k\,c}{k+1}\right)^2 < v(N) \left(\frac{1-k\,c-c}{k+2}\right)^2.$$

Replacing for $k = N - 1$ and $c = 1/N$, the above expression becomes $\frac{N+1}{2N} < 0$, which is a contradiction for $N \geq 2$. ∎

Proof of Proposition 1. The standard is chosen to maximize technical efficiency, which means that $n = N$ under both TU and TEP. However, if a patent pool is formed, $k < n$ under TEP. 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 an example under for which NEP is preferred to NU, and another example for which NU is preferred to NEP.

Consider Example 1. 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 royalty stacking 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, firms choose a technically efficient standard. 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. Consider Example 1 and 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. Consider Example 1 and 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 royalty stacking. Since the technological gain from having $n = 3$ is very small, NU welfare dominates TEP. ∎

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