Effects of Standard Setting Organization Policy on Investment and Welfare

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Abstract

This paper sets out a simple model of the decisions of Standard Setting Organizations (SSOs) and explores the effect of these decisions on investment in new technologies, the degree of technology-sharing among firms, and the pricing of goods that embody these technologies. We find that when complementary technologies are embodied in a standard, equilibrium prices will always lie above optimal prices unless the elasticity of own investment and investment by producers of substitute technologies with respect to own prices prices is significantly positive and there are significant positive spillovers of investment on consumer welfare. We show that technology-sharing may sometimes be socially efficient but privately unprofitable, usually because commitments not to share are a form of commitment to low output levels and therefore to high prices; this is more likely to occur for relatively small innovations. It may sometimes be privately profitable but socially inefficient, because it encourages firms to free-ride on each others' investments. We discuss conditions that determine when sharing will increase investment, and which types of firm will have most to gain from sharing. Technology sharing is not always desirable, but SSOs that are strongly influenced by firms will tend to allow sharing less often than is socially efficient.

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1 Introduction

Firms and consumers requiring complementary IP and technologies from different firms, typically view the establishing of standards as improving efficiency. Moreover, these entities generally would prefer early investments as well as early commitments from those firms developing the new technologies for a standard. The view that cases such as "the information technology standard setting processes . . . " which is ". . . a setting now plagued by a proliferation of anticompetitive patent holdup situations"[1] can benefit greatly from such early commitment. Our purpose in this paper is to explore some of the trade-offs that such decisions involve.

We depart from the conventional view that the standard setting process anoints winners to develop the technologies chosen by the SSO. Instead, we allow for the possibility that investment can occur prior to or subsequent to standard setting decisions. Indeed, this approach seems more consistent with the actual standard setting decisions. In many cases, a de facto standard is developed by a technology innovator long before any formal or official standard is formed, and necessarily before any SSO can anoint winners. Clearly at other times, SSO decisions, especially to develop specific components of an existing technology can contribute to market power.

Three kinds of IP decisions have an important impact on social welfare, and can be taken in ways that are more or less conducive to social welfare. The first is decisions about investment; the second is decisions about sharing of technology between producers, the third is decisions about pricing of the technology to firms using the technology as well as end users, including about whether firms should be able to coordinate their pricing decisions.

Investment decisions can be inefficient for broadly two types of reason. First, investment levels may be inadequate because private returns are below social returns, for instance when one firm free-rides on the investment effort of another because it hopes to benefit from spillovers from the other. Alternatively, investment levels may be excessive because the parties are duplicating each other's efforts when the returns are in the form of a contest, so that there is rent-shifting in favor of the successful innovator.

Decisions about sharing will always be less than first-best efficient, ex post, when they involve anything other than complete sharing of a technology whose marginal cost of diffusion is small or zero. However, ex post first-best efficiency is typically not a realistic standard by which to judge technology-sharing arrangements, because there is an interaction between

[1] see Skitol (2004).

technology-sharing and investment, which means that if all technologies have to be shared there will be diminished incentives to invest in such technologies in the first place.

Decisions about pricing can also be inefficient for several reasons. Prices can be too high because firms enjoy market power. Indeed, some market power is often a necessary condition of excessive pricing (though not always, since optimal prices could lie below competitive prices because of positive externalities). However, in the presence of market power, coordination between firms can be inefficient (and typically will be when the firms mainly produce substitute goods or technologies). However, it can also increase efficiency, when the firms produce mainly complementary goods or technologies.

In this paper we do two main things. First, we analyse rigorously some sufficient conditions for coordination about pricing to be efficiency-enhancing when this takes place among firms that belong to a Standard Setting Organization, and look at how the benefits of coordination may be traded off against some possible costs.

Secondly, we look at the private and social benefits of commitments to share technology. We show that technology-sharing may sometimes be socially efficient but privately unprofitable, usually because commitments not to share are a form of commitment to low output levels and therefore to high prices. It can, at times, be privately profitable but socially inefficient, because it encourages firms to free-ride on each others' investments. We derive conditions that will help determine reasonable policy rules for deciding when allowing firms to make such commitments can improve consumer welfare. As explained below, this analysis has implications about the impact of open source requirements.

2 Related literature

The literature on network effects is well surveyed in Farrell and Kemplerer (2007) and is not relevant in detail to the model developed here.

The literature on Standards Setting Organizations has developed over more than twenty years, but the subject remains still somewhat under-explored. Farrell and Saloner (1988) and David and Greenstein (1988), were among the first papers to deal with the question how standards are, and should be, set. These papers discuss three mechanisms for achieving coordination on the adoption of a standard. One is coordination through a committee where members explicitly communicate and negotiate until an irrevocable choice is made. A second is the opposite of the first: it is a market mechanism where there is no explicit communication and negotiation between competing firms. It succeeds if one firm chooses first and the others follow. Finally a third mechanism is a mix of the two first: both communication and unilateral pre-emptive actions are allowed. Farrell and Saloner model the first mechanism as a "war of attrition" and the second as a "grab the dollar" game, both under complete information. They find that coordination through a committee does better than the market: the latter is faster but the former produces fewer errors (it reaches coordination more often). However they find that the hybrid mechanism is better than the two first because at each period, the game has two chances to produce coordination - and in their model ex ante coordination is desirable.

Coordination can take place in more than one dimension, and there is a literature relating to royalty stacking and hold-up which highlights what can happen when coordination in one dimension (technology choice) is not matched by coordination in another (pricing). This literature begins with the problem of complements highlighted by Cournot. Heller and Eisenberg (1998) discussed the complements problem in the context of biotechnological patents and compared multiple blocking patents problem to a tragedy of the anti-commons. Shapiro (2001) and (2006) highlighted the hold-up problem with standards and Shapiro and Lemley (2007) showed how this problem is magnified in the presence of royalty stacking.

In a later paper, Farrell (1996) returned to the problem of standard setting developed a model of a war of attrition with asymmetric information. There are two firms which have standards of varying quality. Each of the two firms has private information about the quality of its standard. The model predicts that the best standard will be selected because the firm with the better standard will have a higher willingness to wait. The Farrell paper also highlights the role of vested interests: the stronger they are, the more slowly the agreement is reached. David and Monroe (1994) develop an incomplete-information model of war of attrition of the type investigated by Fudenberg and Tirole(1986). Each firm has to choose the time at which it discontinues its proposal. This decision is a function of several arguments: of the payoff it receives when neither sponsor has withdrawn, of the payoff when the other has withdrawn and of its opportunity cost - namely the payoff it gets when it has withdrawn and not the other. The authors derive several comparative statics properties on the probabilities that a firm immediately or never concedes.

Lerner and Tirole(2004) took a different approach and viewed SSOs as certifiers rather as fora for reaching consensus. In their model certifiers differ in their degree of sympathy towards the firm's interests relative to their concern for quality delivered to the users. The choice involves a tradeoff: choosing a tougher certifier decreases the probability of adoption of the standard but makes it more likely to be adopted by users thanks to a better reputation. One of their results is that the weaker the proposed standard is, the more credible is the SSO selected. The model was empirically tested in Chiao, Lerner and Tirole (2005).

Aside from case studies, there are few empirical studies of standard setting. Weiss and Sirbu (1988) examined the determinants of successful proposals. They found, for instance, that the size of the firms in the coalition supporting a technology was significant. Rysman and Simcoe (2008) used patent citations to measure the impact of SSO endorsements. They found that SSOs identify and endorse important technologies and make them last longer.

The literature related to the dynamics of innovation and the incentives to share it is also directly related to these issues. Salant and Cabral (2007) built a model of duopoly in which the technology evolves. At each stage firms can choose to standardize (and thus to share the technology). They find that if gains from innovation are significant, if the short run benefits from standardization are not very high, firms prefer not to standardize, when the discount rate is low. The interim losses from competing standards must be high for firms to commit ex ante to share the results of their innovation, even if there are no bargaining inefficiencies. They also show that an outcome without standardization can be socially optimal. Erkal and Minehart (2008) modelled research projects which can require several stages of innovation, and analyse the link between product market competition and the incentives to share technology at different steps of the innovation process. They show that if competition is relatively moderate (ie duopoly profits are high), the lagging firm is expected never to drop out and the incentives to share decrease monotonically with progress. However if competition is relatively intense (ie duopoly profits are low), incentives to share technology may increase with progress.

There has been a growing literature on open source, which is one of the classic cases of technology sharing. Part of this litrature emphasizes that the benefits to innovators in open source need to be modeled with some care. Lerner and Tirole (2005) argued that open source programmers have a range of motivations. First, open source projects may improve their skills. They can also bring intrinsic satisfaction. They can lead to future jobs, and they can help programmers to signal their talent on the job market. Llanes (2007) extends this analysis with a model in which both open source and proprietary firms coexist. Moreover firms choose their type and also sell a complementary good the quality of which is an increasing function of the amount spent in the open source code. The paper shows that an asymmetric equilibrium can exist even when the firms are symmetric ex ante. In fact there can be equilibria with both kinds of firm, or equilibria with only open source firms. Llanes also shows that the average quality of the goods increases with the number of open source firms because this stimulates the proprietary firms to invest. Most of his results depend on the strength of vertical differentiation relative to that of horizontal differentiation.

Finally Boldrin and Levine (2008) have argued against intellectual property by attacking the traditional assumption that initial research and development costs are high but a new innovation can be copied quite cheaply. In their analysis discovery is modelled as a process which faces decreasing returns to scale. In this world, patents no longer give incentives to firms to invest but decrease the rate of innovation and are thus potentially harmful.

3 A Simple Model

We consider a model in which there are N firms, indexed $i = 1, ..., N$ that can consider investment in a technology. We set out a very general description of the model and the various actions that can be taken by the different players at various stages. Then we shall make a number of specific assumptions about these players, their objectives and their strategies in order to derive particular results.

The model has 6 stages:

In stage 0, the membership and the rules of the standard setting organization ("SSO") are determined. Membership may be open to all or some of the firms participating in a particular market, as well as to all or some organizations representing consumers or other interested parties. The rules of the SSO determine the inclusion of particular components into the specification of a technology, the exclusivity of that technology for use by various downstream users, the sharing or otherwise of components of the technology among members of the SSO, and the royalties that may be charged.

In stage 1, the firms incur their initial investment costs K_i^1 in R&D. This investment need not include all that is required for the technology to be useful in the production of final goods and services. Additional investment will usually be needed to develop the technology.

In stage 2, the firms observe a signal about the stochastic result of their investment $s_i\left(K_i^1\right)$. One form this signal can take is that of an estimate of unit costs of the product that will be produced. The signal can also indicate the potential value of the technology to end users.

In stage 3, the standard setting organization may take an early decision as to which, if any, of these approaches to the technology component to be incorporated into a standard.

In some cases, this may occur when only a small fraction of total development costs have been incurred, while in other cases it will be after a large fraction of these costs are already sunk.

In stage 4, firms can incur their follow-up investment costs K_i^2 in R&D.

Notice that the firms' investment incentives in stage 4 will depend on the rules determined in stage 1 and the SSO decision in stage 3. Firms excluded from the standard in stage 3 can have less of an incentive to invest in stage 4.

In stage 5,

- The firms discover the stochastic result of their total investment $y_i\left(K_i^1, K_i^2\right)$, This result can be interpreted, as above, as the realized unit cost or value to end users.
- Then the standard setting organization makes a final decision as to which, if any, of these technologies to incorporate into the standard, compatibly with its decisions in stage 3. Let $\mathcal{S} \subseteq \mathcal{N}$ denote the set of firms included in the standard.
- The SSO can also establish principles, or add to the conditions established in stage 0 for setting prices, or impose further requirements on firms who own IP included in the standard. The requirements can include
  - Adherence to fair, reasonable and non-discriminatory (FRAND) or reasonable and non-discriminatory (RAND) pricing rules.
  - Ex ante disclosure requirements
  - SSOs can potentially decide that prices p_i must fall in an interval $Q^i \equiv [q_i^-, q_i^+]$. Let $Q = \left([q_1^-, q_1^+], \ldots, [q_i^-, q_i^+], \ldots, [q_n^-, q_n^+]\right)$ be the vector of intervals chosen by the SSO.

In stage 6, prices p_i are set by each firm and payoffs are realized. Let $P = (p_1, .., p_i, .., p_n)$ be the vector of prices set. These will depend, in a manner described below, on the SSO decision and the outcomes of the firms' investments.

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When the standard setting organization has monopoly power (so that firms whose technologies are not included in the standard may not sell in the market), payoffs are realized as $\pi_i^{\mathcal{S}} = \pi_i (y_i, Y_k, P)$ for all firms i included in the standard, where Y_k $(k \neq i)$ is the vector of investments of firms not included in the standard, and $\pi_j = -I_j - J_j$, that is the negative sum of their investment expenditures, for all firms j not included in the standard.[2]

When the technology chosen by the standard setting organization remains in competition with other technologies, payoffs are written more generally as $\pi_i = \pi_i (y_i, Y_k, Y_j, P)$ included in the standard, and $\pi_j = \psi_j (y_j, Y_k, Y_m, P)$ for all firms j excluded from the organization's standard, where $m \neq j$. it is assumed that $\pi_i = \pi_i (y_i, Y_k, Y_j, P) > \psi_i (y_i, Y_k, Y_j, P)$; in other words, it is assumed that it is strictly more profitable for any firm to be included in the standard than to be excluded.

Consumer welfare is written as $C (Y_i, Y_j, P)$ where the $i \in I$ are the included and $j \in J$ the excluded firms. Total social welfare is then

$$W = C(Y_i, Y_j, P) + \lambda(\sum_{i \in I} \pi_i + \sum_{j \in J} \pi_j) \tag{1}$$

where $\lambda \in [0, 1]$ is the weight on profits in the social welfare function.

At stage 5, each firm choose its price i to solve the following problem:

$$\max \pi_i \tag{2}$$

subject to:

$$p_i \in q_i \tag{3}$$

$$p_k \in P, k \neq i \tag{4}$$

The first constraint requires prices to lie in the interval determined by the SSO at stage 4. The second requires that each firm take the other's prices as given. We thereby exclude directly collusive or otherwise coordinated pricing decisions.

[2]This situation will arise when there is a government mandate, as is the case with ETSI and telecommunications in the European Union, or where de facto no technology can possibly compete with that selected by the SSO.

Let P^* be the solution to the problem **??**. Let $P^W = \left(p_1^W, ..., p_i^W, ..., p_n^W\right)$ be the vector of prices that maximizes W. We can now state the following proposition:

Proposition 1: If

a) there are no direct spillover effects to consumers from investment

b) the technologies in the standard $k \neq i \in I$ are weak complements to the technology of firm i, and

c) at least one such technology is a strict complement to that of firm i, and

d) p^* lies strictly in the interior of Q,

then $p_i^* > p_i^W$.

Proof: Appendix

The proposition states simply that uncoordinated pricing by producers of complementary technologies will result, unless constrained by the rules of the SSO, in prices that are above socially optimal levels. This is a slightly more general statement of the well known result by Cournot and is in itself unsurprising. As a matter of policy relevance, its usefulness lies in allowing us to consider how to assess the impact of various departures from the assumptions that generate the result.

The most useful application of Proposition 1 is to considering what happens if there are direct spillover effects to consumers. We can relax assumption a) in Proposition 1. Suppose that $\frac{\partial C(Y_i,Y_j,P)}{\partial y_i} > 0$ for some i (in other words, there are some direct spillovers from investment to consumers - not all the rents are appropriated by the investing firms). Then the strict complementarity of the technologies in I allows us to write that $\sum_{k \neq i \in I} \frac{\partial y_k}{\partial p_i^W} < 0$ so $\sum_{k \neq i \in I} \frac{\partial C(Y_i,Y_j,P)}{\partial y_k} \frac{\partial y_k}{\partial p_i^W} < 0$. Then inequality (**??**) in the proof of Proposition 1 becomes

$$\lambda \frac{d\pi_i}{dp_i^W} + \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial y_i} \frac{\partial y_i}{\partial p_i^W} + \sum_{k \in J} \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial y_k} \frac{\partial y_k}{\partial p_i^W} > 0 \tag{5}$$

whose interpretation is that equilibrium prices will always lie above optimal prices unless the elasticity of own investment and investment by producers of substitute technologies with respect to own prices prices is significantly positive AND there are significant positive spillovers of investment on consumers.

This therefore provides a useful rule of thumb as to when IPR price caps may be welfare improving.

5 Investment Incentives and SSO Policy

In this section we consider the effect on investment incentives and thereby on welfare of an ex ante SSO decision to enforce technology sharing among members of the SSO. We show that even if compatibility is efficient *ex post* (that is, once investments have been sunk), it may be resisted by individuals firms, and it may also lower investment levels.

We specialize our model in a number of ways:

1. There are two firms, using the technology to produce a homogeneous good under a constant marginal cost equal initially to c^0.
2. In stage 0, the SSO can decide that firms participating in the SSO must make their technology available to rivals free of any royalties.[3]
3. The firms' stage 1 investment is directed at process innovation to reduce production costs to $c^1 < c^0$. The two firms choose probabilities x and y of successful innovation, incurring costs of $\frac{x^2}{2k}$ and $\frac{y^2}{2k}$ respectively. The success of the investments is independent (nothing of importance turns on this assumption).
4. There is no stage 2 signal, no stage 3 decision by the SSO, and therefore no stage 4 investment.
5. At stage 6 the firms compete in outputs, and prices are determined by a linear inverse demand function. $p = A - Q/9$ where p is price and the $Q = q + 1 + q_2$ is the sum of the firms' quantities supplied.

We begin by solving for the outcome of competition in stage 6. When firms' have marginal costs (c, d), the firm with costs c will have profits excluding investment costs equal to

$$\pi(c, d) = (A - 2c + d)^2 \tag{6}$$

We can then consider the effect on joint firm profits of sharing technology ex post. If both firms succeed, which occurs with probability xy, it makes no difference whether they share or not, they will both produce at cost c^1, and make profits each of $(A - c^1)^2$

[3] Or at some pre-set royalty.

Similarly, if both firms fail, which occurs with probability $(1-x)(1-y)$, it makes no difference whether they share or not, as they will both produce at cost c^0, and make profits each of $(A-c^0)^2$.

However, if the first firm succeeds and the second fails, which occurs with probability $x(1-y)$, the first firm will make profits of $(A-2c^1+c^0)^2$ while the second makes smaller profits equal to $(A-2c^0+c^1)^2$

If the second firm succeeds and the first fails, which occurs with probability $y(1-x)$, the first firm will make profits of $(A-2c^0+c^1)^2$ while the second makes larger profits equal to $(A-2c^1+c^0)^2$.

Thus for the first firm, the difference in expected profits due to sharing, before knowing whether its investment will succeed or fail, will be given by the expression

$$E\Delta\Pi_1^S = x(1-y)\left[(A-2c^1+c^0)^2-(A-c^1)^2\right]+y(1-x)\left[(A-2c^0+c^1)^2-(A-c^1)^2\right] \tag{7}$$

and similarly for firm 2 :

$$E\Delta\Pi_2^S = y(1-x)\left[(A-2c^1+c^0)^2-(A-c^1)^2\right]+x(1-y)\left[(A-2c^0+c^1)^2-(A-c^1)^2\right] \tag{8}$$

Simplifying yields:

$$\begin{aligned} E\Delta\Pi_1^S &= x(1-y)\left[\left((A-2c^1+c^0\right)^2-(A-c^1)^2\right] \\ &\quad +y(1-x)\left[(A+c^1-2c^0)^2-(A-c^1)^2\right] \\ &= x(1-y)\left[(2A-c^1+c^0)(c^0-c^1)\right]+ \\ &\quad y(1-x)\left[4(c^1-c^0)(A-c^0)\right] \end{aligned} \tag{9}$$

For the symmetric case where $x=y$,

$$E\Delta\Pi_1^S = 4x(1-x)(c^0-c^1)(5c^0-c^1-2A) \tag{10}$$

When $5c^0-c^1>2A$, this will be positive.

We can summarize the result in the following Proposition:

Proposition 2: In the unique symmetric equilibrium of the two-firm, homogeneous good, linear-demand Cournot competition version of the model, an SSO seeking to maximize joint industry profits is more likely to choose to require royalty-free technology sharing if initial costs are high, and cost-savings from the innovation large, relative to the intercept of the inverse demand function.

Two features of this result should be noted:

1) The result would not hold in a Bertrand model with homogeneous products and competition in prices. Under these circumstances, the firms will earn zero profits if they invest in the same standard, and must each permit the other to use the others IP.

2) Given the investment levels, non-sharing is always bad for consumers (as well as for efficiency). This is because non-sharing acts as a commitment to lower output in the circumstances where one of the investments succeeds and the other fails. Nevertheless, non-sharing may be privately profitable even if socially inefficient, provided the cost reduction is small compared to the existing consumer surplus.

So does it follow that the authorities should impose sharing? No! The reason is that sharing may dilute investment incentives, since each firm has an incentive to free ride to some extent on the investments of the other.

To see this, we solve for the investment decision at stage 1, conditional on whether or not the SSO has decided to impose technology sharing. If there is sharing the first firm chooses x to solve

$$Max_x \left[(x+y-xy)(A-c^1)^2+(1-x)(1-y)(A-c^0)^2\right]-\frac{x^2}{2k} \tag{11}$$

while if there is no sharing it chooses x to solve

$$Max_x \left[xy(A-c^1)^2+x(1-y)(A-2c^1+c^0)^2+y(1-x)(A-2c^0+c^1)^2+(1-x)(1-y)(A-c^0)^2\right]-\frac{x^2}{2k} \tag{12}$$

The first order conditions for problem (**??**) are:

$$\begin{aligned} x^S &= k(1-y)\left[(A-c^1)^2-(A-c^0)^2\right] \\ &= k((1-y)\left[2A-c^0-c^1\right] \end{aligned} \tag{13}$$

and those for the problem (**??**) are

$$\begin{aligned} x^{NS} &= k\left[y(A-c^1)^2+(1-y)(A-2c^1+c^0)^2-y(A-2c^0+c^1)^2-(1-y)(A-c^0)^2\right] \qquad (14) \\ &= k(1-y)\left[(A-2c^1+c^0)^2-(A-2c^0+c^1)^2-(A-c^0)^2\right]+ky\left[(A-c^1)^2-(A-2c^0+c^1)^2\right] \\ &= k4k(c^0-c^1)\left[(1-y)(A+c^0-c^1)+y((A-c^0)\right] \end{aligned}$$

Thus the difference between investment incentives under sharing and no sharing can be written:

$$x^{NS}-x^S=k(c^0-c^1)\left[(1-y)(2A+5c^0-3c^1)+y(A-c^0)\right] \qquad (15)$$

which is positive as long as $A > c^0$, which is required if price can ever exceed initial marginal costs. This result therefore holds whether or not the conditions of Proposition 2 are satisfied. We can summarize this in the following Proposition:

Proposition 3: In the unique symmetric equilibrium of the two firm, homogeneous good, linear demand, Cournot competition version of the model, if investment costs are quadratic, investment is higher without sharing whether or not the firms prefer sharing conditional on investment.

This reflects a general trade-off. Sharing of an already existing technology, via an ex ante commitment enforced by an SSO, benefits consumers and has a direct benefit for firms (call this the diffusion effect). But it also has two indirect effects that firms dislike: one is to make them compete more strongly (call this the competition effect, which is good for consumers and overall social welfare), while the second is to make them free-ride on each other's investment incentives (call this the investment effect, which is bad for all parties). Commitments to share can therefore sometimes be good for overall welfare (when the diffusion and competition effects are strong compared to the investment effect). But they may be bad for welfare if the investment effect is relatively strong, and it is a mistake to think that they should be imposed as a matter of course. In addition, firms are likely to wish share less often than is socially beneficial, because they dislike the competition effect, and they also do not internalize all the benefits from the diffusion effect. Thus SSOs that are strongly influenced by firms may impose technology sharing less often than is socially efficient.

Clearly, this result is sensitive to the form of the innovation function. For example, suppose that a small investment is required to adequately compensate for investment without ex ante commitment to sharing, but that a larger investment would be consistent with the higher ex ante success probability with sharing. That is, investment costs can be low,L, in which case there is a small probability of innovation, or high, H, in which there is a high probability of innovation.

Notice that with each firm having a stand-alone probability p of innovation, and sharing of technology, the probability of achieving success is $2p(1-p) > p$ for $p \in (0, \frac{1}{2})$.

This means that the expected payoff from sharing is

$$\Delta\pi^{HS} 2p^H(1-p^H) - H. \tag{16}$$

In contrast, the expected payoff from not sharing and a low level of investment is

$$p^j \Delta\pi^{jNS} - j \tag{17}$$

where p^j is the probability of innovation with investment level $j = L, H$, and $\Delta\pi^{jk}$ is the increase in profits with innovation with investment level $j = L, H$, and sharing decision $k = NS, S$.

With a high $\Delta\pi^{HS}$, and not too high H, it is possible that

$$\Delta\pi^{HS} 2p^H(1-p^H) - H > max\{p^L \Delta\pi^{LNS} - L, p^H \Delta\pi^{HNS} - H\}. \tag{18}$$

(**??**) is the condition for sharing to be more profitable ex ante. Summarizing

Proposition 4: In an equilibrium of the two-firm competition version of the model, firms will each prefer ex ante sharing if and only if investment costs satisfy (**??**).

This condition does not really specify the source of the profitability of sharing or not sharing. This is a very reduced form expression. For instance, if a firm is vertically integrated in a downstream market, its downstream market share may be adversely affected by sharing.

The above proposition does not explicitly consider differences across firms. Such differences are common in practice. For example, the 3G standard setting process included firms that had different shares in upstream and downstream markets. Nokia contributed technology toward 3G, but was also a licensor of that technology for its handsets and equipment. Other firms, such as Alcatel-Lucent specialize more in network equipment. Still other firms, such as QUALCOMM, largely provided technology in exchange for license fees. The terms $\Delta\pi^j, j = L, J$ will differ depending on how integrated such firms are. Thus, a firm whose profits derive more from the equipment and handsets in downstream markets would tend to favor ex ante sharing, as they have relatively little difference in profits between sharing and not-sharing ex post, and would prefer high investment levels. Conversely for a firm whose profits mainly from the technology, which may have the most to lose from sharing

Another example from the wireless industry is the Google Android operation system as compared to the Apple iOS. Google is largely focused on advertising revenues, and appears to invest in mobile operating systems as a a means of selling more ads. This suggests that its profits are not very much affected by whether the technology is open or not (except for the web browsers). In comparison, Apple derives much of its profit from handsets and tablets, and would be very adversely affected by sharing. In other words, Apple's $\Delta^{jNS} - \Delta^{jS}$ will tend to be high relative to Google's.

These types of consideration are not unique to the wireless industry, but have arisen over several generations, going back at least as far as the video tape recording formats, such as VTR, VHS, Beta, DVD, DIVX and more recently on MPEG, Windows Media Player, Apple Quicktime. These type of issue have also arisen for many other technologies - DRAM and Rambus being a very recent notable example.

6 Welfare and Sharing

The above section indicates that non-sharing can result in higher investment than would occur if sharing were mandatory ex ante. Here we address the optimal policy. Assuming that the SSO policy is set to maximize the sum of consumer surplus and firm profits, then the question is whether welfare is higher with mandatory sharing than without. The SSO will see lower investment, and less innovation, in some cases, when it requires technology sharing.

The change in welfare from sharing is equal to

$$\rho^h(2-\rho^h) \times W^h - \rho^l(2-\rho^l) \times W^l$$

When the above expression is positive, then welfare will be higher without sharing than with sharing, and vice versa.[4] However, when a sharing requirement (of the open source and/or FRAND-type) does not affect firm investment incentives, then welfare is unambiguously higher with ex ante sharing requirements.

Note that the SSO decision is not necessarily about whether or not to require technology licensing; rather the timing and the terms can potentially be affected by an SSO or, in some

[4] Cabral and Salant (2011) have a similar result in a slightly different context.

cases, by a regulatory mandate. In general, as we have discussed above, consumer welfare is higher, ex post, with sharing. On the other hand, investment can be reduced.

We have assumed above that the SSO has only two stages, or dates, at which it can make a decision about sharing. This is of course a simplification. We now consider what the optimal outcome may be if the SSO has one or more later dates, $t_1, t_2, \ldots, t_n$, at which it can choose to impose or begin enforcing a sharing requirement.

Suppose in (18) above, the firms would, under a sharing requirement, invest at level L, but would invest in H absent sharing. Call this the assumption of Discrete Efficient Investment: either no investment takes place or it takes place at the efficient level. Further suppose that $\pi^j = \int_0^{infty} R^j e^{-rt} dt, j = L, J.$ that is, the payoff is derived as discounted sum of future revenues (and R^j is revenue per unit time).

Now let $\pi^j(t)$ denote the profits when sharing is imposed as of date t when investment is $j = L, H$. What is clear then is that if t is sufficiently large, then the condition (18) is unchanged, and setting $t = 0$, is equivalent to requiring sharing in Stage 6.

Note that the term $\pi^H(t) - \pi^L(t)$ is continuous in t. Thus, if this term is positive for $t = \infty$, i.e., when no sharing is required, and negative for $t =$, i.e. under full sharing, then there must be a date t^* such that the firms will choose to invest H whenever $t \geq t^*$ and L otherwise. So, if the SSO can delay the sharing mandate to some later stage, and date $t > t^*$, the firms will invest at level H.

Thus the optimal SSO policy is as follows:

Proposition 5: An SSO should always mandate ex ante sharing of technology when that decision does not alter R &D investments. If the Discrete Efficient Investment assumption holds and if investment will not take place if sharing is mandated early, *and* social welfare is lower if the investment does not take place, then the optimal policy is to delay sharing requirements up to the point at which firms would just be willing to incur the higher investment levels.

7 Policy Implications

We have introduced a framework intended to be useful for analyzing the policy effects of different types of standard setting decisions. Because of the increasing impact of standard setting organization decisions on diffusion of new technologies, discussion about reform of standard setting organizations has been increasing. Moreover, policy toward such organizations varies across technologies and across countries. The framework and the analysis of this paper can be a useful starting point in evaluating the appropriate policy toward standard setting.

Our analysis has focused on those standard setting decisions in which investment is required, and in which coordination is not the only goal of the standard and participants of the standard setting organization. We have only tried to capture a single phase of standard setting processes; in reality, standards are very dynamic, often changing frequently over time. This creates issues of strategic timing that are absent from our simple framework.

The policy questions have been and remain quite contentious. Practice differ markedly across sectors and across countries. For example, in the European Union, the European Telecommunications Standard Institute ("ETSI") has been delegated the authority to set what are effectively mandatory standards for most of the significant wireless communications systems, including the 2G, 3G and 4G frequencies. In contrast, in most of the Americas, India, and a few other countries, the choice of standard has been left to the market. In still other countries, such as China, the choice of standard is determined by government award of frequency to an operator. Further, in many sectors, especially for web-based technologies, there are many who favor compulsory sharing in the form of open source ex ante commitments.

Clearly, these are different policies, and this paper is intended to provide an initial framework for analysing what types of policies can be most effective in different circumstances. The model we provide is also intended to highlight the impact differences across standards and technologies can have on effects of different policies toward sharing and licensing.

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9 Appendix

Proof of Proposition 1: The first order condition that p_i^W must satisfy is

$$\frac{dW}{dp_i^W} = \frac{dC\left(Y_i, Y_j, P\right)}{dp_i^W} + \frac{d\lambda \sum_{i\in I} \pi_i + \sum_{j\in J} \pi_j}{dp_i^W} = 0 \tag{19}$$

The first term on the RHS can be analyzed as follows:

$$\begin{aligned} \frac{dC\left(Y_i, Y_j, P\right)}{dp_i^W} &= \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial p_i^W} + \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial y_i}\frac{\partial y_i}{\partial p_i^W} \\ &+ \sum_{k\neq i\in I} \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial y_k}\frac{\partial y_k}{\partial p_i^W} + \sum_{k\in J} \frac{\partial C\left(Y_i, Y_j, P\right)}{\partial y_k}\frac{\partial y_k}{\partial p_i^W} \end{aligned} \tag{20}$$

The second term can be analyzed as

$$\frac{d\lambda \sum_{i\in I} \pi_i + \sum_{j\in J} \pi_j)}{dp_i^W} = \lambda \left\{ \frac{d\pi_i}{dp_i^W} + \sum_{k\neq i\in I} \frac{d\pi_k}{dp_i^W} + \sum_{j\in J} \frac{d\pi_j}{dp_i^W} \right\} \tag{21}$$

We can now proceed to sign the components of this first order condition.
First, assumption a) implies that $\frac{\partial C(Y_i,Y_j,P)}{\partial y_i} = 0$ for all i.

Second, assumptions b) and c) together imply that $\sum_{k\neq i\in I} \frac{d\pi_k}{dp_i^W} < 0$.

Third, $\frac{\partial C(Y_i,Y_j,P)}{\partial p_i^W} < 0$.

Third, although $\sum_{j\in J} \frac{d\pi_j}{dp_i^W}$ is likely > 0 if some $j \in J$ are substitutes for technology i, $\frac{\partial C(Y_i,Y_j,P)}{\partial p_i^W} + \sum_{j\in J} \frac{d\pi_j}{dp_i^W} \leq 0$ by an argument from the optimization of firms $j \in J$. Consider an infinitesimal increase in p_i^W. If for some j, $\frac{d\pi_j}{dp_i^W} > 0$ this is because some consumers switch from i to j. $\frac{\partial C(Y_i,Y_j,P)}{\partial p_i^W}$ represents the (negative of the) consumer surplus those consumers would lose if they stayed with i, while $\frac{d\pi_j}{dp_i^W}$ is the profit they actually bring to j. The latter cannot be greater than the former because otherwise j could have made strictly greater profits prior to the change in p_i^W by some small reduction in its price p_j^W. Such a reduction would be feasible by assumption d).

Collecting the unsigned terms, we can therefore use equation (**??**) to derive the inequality

$$\lambda \frac{d\pi_i}{dp_i^W} > 0 \qquad (22)$$

which by the concavity of the profit function in prices implies that $p_i^W < p_i^*$. QED