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STANDARDIZATION AND EXPERIMENTATION: EX ANTE VERSUS EX POST STANDARDIZATION

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Standardization and Experimentation:
Ex Ante vs. *Ex Post* Standardization

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Abstract

This paper develops a framework to investigate the optimal timing of standardization in which the tradeoff between standardization and experiment is explicitly analyzed. *Ex ante* standardization ensures early benefits of compatibility while the standard chosen could be a "wrong" one since the decision is made without precise information about the actual values of potential technologies. *Ex post* standardization relies on the market mechanism to achieve *de facto* standardization after experimentation. The advantage of this approach is that the standardization decision can be based on better information about qualities. The cost is the transient loss of compatibility benefit in the experimentation stage. The market outcome is shown to generate too little *ex post* standardization after experimentation compared with the social optimum. Consequently, users adopt *ex ante* standardization too frequently compared with the social optimum. The model can be also reinterpreted as an analysis of the tradeoff between standardization and innovation.

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1. Introduction

In many high-tech industries, such as telecommunications and the computer, compatibility plays an increasingly critical role in harnessing potential demand-side scale economies, now known as network externalities. Standardization is one obvious way of achieving compatibility. By choosing the same interface or sharing the same technical specifications in key components, products from different manufacturers can be combined and used in a harmonious way to exploit network externalities.[1] Standardization, however, is not without its costs, especially if the standards are set in the early stages of the technological cycle, when the values of competing standards are not fully known. Since new information about qualities can be available only over time, we cannot claim that early standardization is better than late unless the same standard is set. Moreover, nascent technologies often have the property that information on their true values is hard to assess without actually using it [Rosenberg (1982)]; only after tinkering and experimenting with them, will the potentials or hazards of the technologies be revealed and can a clear picture of the optimal standard be projected. As a consequence, there is an inevitable tradeoff between standardization and experimentation. Early standardization implies ill-informed decision-making on standards, while delayed standardization after experimentation involves at least transient losses from incompatibility between the technologies that are experimented with.

This paper develops a framework to investigate the optimal timing of standardization in which the tradeoff between standardization and experiment is explicitly analyzed. I consider two possible approaches to achieving standardization in a two-period

[1] As emphasized by Gabel (1991), standardization is not the only way of creating compatibility. An alternative way to achieve compatibility, which has not been fully developed in the literature, is through the development of converters that allow consumers of one network to utilize the network benefits of another. We ignore the possible availability of converters in this paper. For recent treatments of converters in technology adoption, see Farrell and Saloner (1992) in a static context and Choi (1993a) in a dynamic setting. David and Bunn (1988) provide an interesting case study of converters, which they call gateway technologies, for electric supply systems.

model. In the first, which I call *ex ante* standardization, potential users agree on selecting the same technology without knowing the exact values of alternative technologies. The advantage of this approach is that they can have the full benefit of compatibility from the beginning. However, their choice, based as it is on limited discriminating power, could easily be an inferior one. The other approach is to rely on the market mechanism to achieve de facto standardization after experimentation, which I call *ex post* standardization. The advantage of this approach is that the standardization decision can be based on better information. The process of *ex post* standardization, however, can fail and incompatibility between the experimented technologies can persist. The reason is that in the process of experimentation each firm's preferences start to diverge. Each firm can accumulate technology-specific complementary goods and acquire specific knowledge on and experience with the technology it has used (experimented on).

The examples of Integrated Services Digital Networks (ISDNs) and Local Area Networks(LANs) illustrate two distinct approaches to standardization. Since its inception, the ISDN standards have been characterized by the network planning approach, always addressing issues of interconnection and interoperability. The activities involved all participants of the industry for the purpose of specifying a consentient set of interfaces that could serve as the cornerstone of a new network service. In contrast, LANs started as different vendors offered incompatible versions of the product. As a result, an open interconnection across user groups has been difficult. However, LAN standards are now being developed and established as more information is revealed regarding the merits of each technology [see Lifchus (1986) for more details].

I compare private incentives to choose one of the two approaches with those of a social planner. It is shown that there are social inefficiencies associated with the *ex post* standardization process; there is too little ex post standardization compared with the social optimum due to the positive externality that is not accounted for in the decision-making of an individual. In contrast, I do not expect that ex ante standardization suffers the same problems since participants have not built up any vested interests and have the same preferences.[2] As a result, potential users will adopt the option of ex ante standardization over experimentation too frequently compared with the social optimum if the participants foresee the inefficiency of ex post standardization accompanying experimentation.[3] Our analysis demonstrates the need for a new taxonomy of the standardization processes.

In this paper, I envision a situation in which no participants have any competitive advantage in any particular technology by the time a standard-setting committee is convened to decide which type of approach to take for the standardization problem: *ex ante* or *ex post* standardization. Since homogeneous preferences and symmetric information are assumed across participants, there is no conflict among participants. I expect a consensus to be reached without any delay. My paper, therefore, differs from Farrell and Saloner (1988) in the initial conditions for the formal negotiation process analyzed and, as a result, in its focus. They consider a situation in which participants already have vested interests in incompatible positions by the time formal negotiation takes place through a committee. Their focus is on comparing the performance of the committee with that of the market in arriving at a standard and resolving the conflict.[4] In contrast, I allow participants to communicate before they take up any particular positions on possible standards.[5]

[2]In my model, vested interests in the *ex post* standardization process is captured by the "switching costs" à la Klemperer (1985, 1987). If there are no switching costs to be borne by individual users, we will have efficiency as in Farrell and Saloner's (1985) adoption model with complete information. In addition to the existence of network externalities, my model is also different from Klemperer's in that there is uncertainty about the qualities of products.

[3]In this regard, the conclusion of my paper contrasts sharply with that of Lifchus (1986) who advocates an *ex ante* standardization process over experimentation based on the case studies of ISDNs and LANs. Our analysis clearly shows the danger of an *ex post* judgement for the standardization process when uncertainty is involved in the qualities of the potential technologies.

[4]They also analyze the performance of a hybrid system in which coordination failure in the committee is followed by potentially unilateral movement by participants. It is shown that the hybrid system performs best as a coordination mechanism.

[5]Note that in this paper we rely only on unilateral market forces for *ex post* standardization once the option of experimentation is chosen by participants. However, this is a stronger assumption than we really need; all the analysis requires is that there should be divergence

There are two ways to interpret our model. First, my model is appropriate for situations where the potential technologies to choose from are in the public domain. Then, it is not unreasonable that the technologies are approximately neutral in terms of strategic competition. The type of research performed at universities or in government-funded projects, the outcome of which is publicly available, would fall in this category. However, we can also apply the analysis to situations in which proprietary technologies are developed by private firms. In this case, standardization can be interpreted as a joint effort to develop a new technology that is equally accessible to all participants, which ensures standardization once the technology has been developed.[6] Experimentation, in contrast, translates into an individual and proprietary development of the technology. Independent developments without communication usually mean distinctive approaches to the problem and generates the benefit of "sampling effect" in innovation. Final outcomes of independent developments will, however, tend to be incompatible with each other.[7] In this respect, we can reinterpret the model as an analysis of the tradeoff between standardization and innovation.

Other types of potential costs associated with standardization have also been recognized in the literature. The most prominent is the tension between standardization and variety. Farrell and Saloner (1986), for instance, analyze the tradeoff in a model of two types of consumers whose preferences differ in their ideal specifications of the good. The cost of standardization is a constraint on product variety: it is necessary for one type of

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between the social and private incentives. We can easily embed the analysis of Farrell and Saloner (1988) in our model for *ex post* standardization. Our paper and Farrell and Saloner's should, therefore, be viewed as complementary in that they focus on different aspects of committees. Their focus is more on the role of standard-setting committees in their conflict resolving ability, while my paper emphasizes their role as a simple coordination mechanism like a "correlated" device.

[6]CD (compact disk) technology is the result of such an effort between Sony and Philips.
[7]CC (compact cassette) technology is such an example. Philips has developed the DCC (digital compact cassette) technology while Sony has developed MD (mini disc). They are incompatible with each other.

consumers to consume the less ideal version of the good to attain a larger network benefit.[8] They demonstrate that there can be too much or too little variety as in the literature on monopolistic competition [see Dixit and Stiglitz (1977) and Spence(1976)]. In a recent paper, Farrell and Saloner (1992) extend the analysis to a continuum of consumer types and investigate the implications of converters for the tradeoff between compatibility and variety.

Technical progress may be another casualty of standardization since it may constrain the freedom to design and introduce optimal products.[9] As argued earlier, our model can be easily reinterpreted as an analysis of this tradeoff. In the context of international competition, Jensen and Thursby (1992) provide a dynamic model in which two firms compete over time over a discovery of a new standard. They examine the impact of standards set *before* products are successfully developed. In particular, they point out that simple standards are time-inconsistent because consumers are hurt when products ruled out by a simple standard are discovered before the discovery of the product set as the standard.[10] Their main interest lies in analyzing the impact of anticipatory product standards on the strategic position of firms in an international patent race.

In an earlier paper [Choi (1994b)], I consider the technology adoption process in which *sequential* arrival of users creates intergenerational heterogeneity in the preferences. Differences in the assumptions on the nature of technological uncertainty allow the waiting option to be explicitly analyzed. One of the results is that consumers who arrive early

[8]In the "mix-and-match" model of Matutes and Regibeau (1988), the interface compatibility and variety go hand in hand. Compatibility between complementary components of "systems" aids consumers in constructing their ideal system by mixing and matching individual components purchased separately. The consequence of (mixed) bundling in the framework of the "mix-and-match" model is discussed by Matutes and Regibeau (1992).

[9]See Lifchus (1986) for a different viewpoint on this issue. He argues that standardization stimulates innovation by forcing firms' competitive decisions to "be based on factors such as price, functionality and performance rather than specific design and availability considerations."

[10]A simple standard is defined as one that is not state-contingent. Jensen and Thursby (1992) further show that the only type of standard which can unambiguously increase welfare is one that is state-contingent.

adopt one of the available technologies too soon. While the option of waiting does not provide any new information on untested technologies in the current paper, the value of each technology, which evolves over time, is revealed at the beginning of each period regardless of its adoption history. In this sense, information is free and waiting can be a valuable option. However, in that paper, experimenting and changing the allegiance to technologies is not possible since technology adoption is assumed to be *irreversible*. In contrast, Choi (1994a) and Waldman (1993) both consider the case where an investment or adoption decision is not irreversible and consumers are allowed to make repeat purchases as in this paper. Their interests, however, are in the monopolistic supplier's incentive to make products incompatible to induce repeat purchases on the basis of network externalities, which they call planned obsolescence.

The paper is organized in the following way. In Section 2, I outline the formal model. I first identify the inefficiencies in the second period when the option of experimentation is chosen in the first period. Typically, there will be too little *ex post* standardization via de facto standards. Since these inefficiencies will be foreseen in the first period, I derive the result that there will be too much *ex ante* standardization compared with the first-best. I also perform some comparative statics on the relative merits of experimentation vis-à-vis (ex ante) standardization. Section 3 considers special two point distributions to generate a closed form solution. I demonstrate that experimentation is more attractive as the correlation in the values of the two technologies decreases. Concluding remarks follow, in which possible extensions of the present model are discussed.

2. The Model

In this section, I present a simple model of standardization problems facing potential users of technologies exhibiting network externalities. There are two time periods, t=1, 2. There are also two potential users, 1 and 2 who can choose between two competing and incompatible technologies, A and B. I denote by Δ the value each user attaches to the network externalities conferred when the other user adopts the same technology. The stand-alone values of these two technologies, however, are unknown to the potential users. They will be revealed only after the corresponding technologies have been used. This assumption captures the idea that the potential values of many technologies can be ascertained only after they have been put to actual use. In the course of being used, new ways of utilizing the technology can be found and/or new obstacles can appear [see Rosenberg (1982)].

Let α and β denote the values of technologies A and B, respectively. They are nonnegative real numbers and are assumed to be drawn from a joint probability distribution $G(\alpha,\beta)$. In order to expedite the presentation, I also assume that the joint distribution function $G(.,.)$ is symmetric in its arguments. Therefore, before the technologies are used and their real values are revealed, they are considered equally attractive. Finally, the values of the technologies are assumed to be constant across two periods.[11] The discount factor is denoted by δ.

In the second period, the qualities of all technologies used in the previous period become public information. In light of new information available in the second period, each user has the option of adhering to the technology he used in the first period or changing his allegiance to the other technology. I assume that switching to the other technology entails a switching cost of s because the adoption of technology is often accompanied by technology-specific learning and /or investment in complementary products [Cowan (1990), Church and Gandal (1992)].[12]

For simplicity, we make the following assumption: Let $h(\beta|\alpha)$ be the conditional density function for β given the value of α. Then,

[11]Choi (1994b), in contrast, analyzes the case where the values of technologies evolves over time.
[12]See Klemperer (1985, 1987) for other types of switching costs and their implications for market conduct and performance.

$$\alpha > \int \beta\, h(\beta|\alpha)d\beta - s, \text{ for all } \alpha \tag{1}$$

When both users adopt the same technology A in the first period, the true value of technology B is still unknown in the second period. Conceivably, in the second period they can change their standard if the value of technology A turns out to have too low a value compared with the expected value of technology B. The assumption, however, says that neither will have incentive to switch to technology B in the second period since the conditional expected value of technology B does not justify the switching cost. Due to the symmetry of distribution function G(.,.), the same parallel argument can be made when both users adopt technology B in the first period. Taken together, the assumption guarantees that there will be no change in the standard in the second period if both users adopt the same technology in the first period.[13]

The game proceeds in the following way. Potential users convene before the game to discuss how to standardize between the two competing and incompatible technologies, A and B. I assume that the users have the same preferences toward the technologies.

I consider two possible ways of achieving compatibilities by standardization. The first is what I call *ex ante* standardization, in which the two users agree to choose the same technology in period 1 without knowing the exact values of each technology. Since they have no vested interests in any particular technology and share the same preferences, there will be no coordination problem: cheap talk is sufficient to ensure consensus.[14] However, they need not set a standard in the first period. They may agree *not* to standardize, thereby opting for each party to experiment with different technologies. When the values of these two technologies are known after the first period, they can hope for *de facto* standardization to occur *ex post*. The tradeoff between these two approaches

[13]This assumption is not crucial to the main results of the paper and can be easily dispensed with.

[14]We ignore the possibility of "babbling equilibria" in which everybody talks nonsense and refuses to listen.

is clear. Ex ante standardization ensures the benefit of compatibility from the beginning of the technological cycle. However, the standard is set with limited information. Experimentation with different technologies allows them to settle for a standard with better information. The cost of experimentation is the initial loss of compatibility benefit. On top of it, there is no guarantee that a de facto standard will be set even after what the full potential of each technology is known and which technology is the best. The reason is that in the process of experimentation, each user starts to acquire vested interests in the technology he has experimented with. As a consequence of this conflict, the initial incompatibilities may persist. This captures the idea that delayed standardization is difficult [Farrell and Saloner (1987)].

2.1. Experimentation

To analyze the expected value of each option, the second period problem should be addressed first. Suppose that the potential users decide to experiment with different technologies. Without loss of generality I assume that user 1 chooses technology A and user B chooses technology B in the first period. Let us denote α and β as the values of technologies A and B, respectively, revealed after experimentation. In period 2, each user has the option of adhering to the technology he used in the first period or changing his allegiance to the other technology. Accounting for the switching cost, I can write the payoff matrix for the second period game as in Figure 1.

[Insert Figure 1 about here]

There are four *possible* outcomes: (NS, NS), (NS, S), (S, NS), (S, S). The first and second components correspond to the strategies for user 1 and user 2, respectively, where S stands for the switch to the other technology and NS represents the strategy of holding onto the technology used in the first period. We have the following proposition regarding the equilibrium in the second period when users agree to experiment in the first period.[15]

Proposition 1. In the Ex Post Standardization game,

(i) If $|\beta - \alpha| < s - \Delta$, (NS, NS) is the unique Nash equilibrium.

(ii) If $\beta - \alpha > |s - \Delta|$, (S, NS) is the unique Nash equilibrium.

(iii) If $\alpha - \beta > |s - \Delta|$, (NS, S) is the unique Nash equilibrium.

(iv) If $|\beta - \alpha| < \Delta - s$, there exist multiple equilibria. (S, NS) and (NS,S) are both equilibria and there is also a mixed strategy equilibrium. If the mixed strategy equilibrium is played, player 1 plays switching with probability of $\mu_1 = \frac{(\alpha-\beta)+(\Delta-s)}{2\Delta}$ and player 2 plays with $\mu_2 = \frac{(\beta-\alpha)+(\Delta-s)}{2\Delta}$. Both players get the same expected payoffs of $\frac{(\alpha+\beta)+(\Delta-s)}{2}$.

Now analyze the socially optimal outcome in the second period given the values of α and β. If neither of them switches, the social value is given by $\alpha + \beta$. If there is standardization on technology A or B, the value is given by $2(\alpha + \Delta) - s$ and $2(\beta + \Delta) - s$, respectively. Therefore, we have the following socially optimal rule for (*ex post*) standardization.

Proposition 2.

(i) (NS, NS) is socially optimal if and only if $|\beta - \alpha| \leq s - 2\Delta$.

(ii) (S, NS) is socially optimal if and only if $\beta - \alpha \geq s - 2\Delta$ and $\beta > \alpha$.

[15] We do not allow side-payments in the ex post standardization game. Gabel (1991) claims that "in practice side payments feature much more commonly in economic journals than in industry." He attributes the efforts of the OSF (the Open Software Foundation) to settle on a competitively neutral standard to the infeasibility of a side-payment scheme for a non-neutral one.

(iii) (NS, S) is socially optimal if and only if $\alpha - \beta \geq s - 2\Delta$ and $\alpha > \beta$.

Comparing the Nash equilibrium outcome with the socially optimal one, I can identify two kinds of inefficiencies according to the sign of $\Delta - s$, as shown in Figure 2.

[Insert Figure 2 about here]

In the horizontally hatched area, the socially optimal outcome recommends standardization by having the user of the inferior technology switch to the other user's technology. However, in the equilibrium outcome no switching occurs. Therefore, there is too little *ex post* standardization in the market economy. The reason is related to the familiar positive externality argument. When one party switches to the other technology to ensure compatibility, he confers positive network externality to the other party. This effect is ignored in the private decision problem. In the dotted area, the socially optimal outcome is once again standardization on the better technology. However, they may end up standardizing on the wrong technology if the user of the inferior technology insists on his technology as the standard. In the mixed strategy equilibrium, there may be an additional coordination failure resulting in the *ex post* nonstandardization: neither may switch or both may switch.[16] As will be shown below, the consequences of these inefficiencies result in two parties deciding on early standardization too frequently.

Given the equilibrium outcome of the second period, we can derive the expected value of experimentation summed over two periods. Let $\Omega = \{(\alpha, \beta) ; (\alpha, \beta) \in R^2_+\}$ be the set of the possible values of the technologies revealed after use in period 1. Define the following subsets of Ω:

$$E_\alpha = \{(\alpha, \beta) ; \alpha - \beta > |s - \Delta|\}$$

$$E_\beta = \{(\alpha, \beta) ; \beta - \alpha > |s - \Delta|\}$$

[16]As one referee pointed out, if we introduce explicit dynamics in the *ex post* standardization process, the game will exhibit the payoff structure of a "chicken game." Then, there may be another type of inefficiency arising from delay in standardization. The expected payoffs from playing this "chicken game", however, will be similar to the ones from using mixed strategies in the static game. As a result, there will be no change in any conclusions drawn in the paper.

$$E_{\alpha} = \{(\alpha, \beta) ; \alpha - \beta > [s - 2\Delta]_+\}$$

$$E_{\beta} = \{(\alpha, \beta) ; \beta - \alpha > [s - 2\Delta]_+\}, \text{ where } [x]_+ = \max(x, 0).$$

E_{α} (E_{β}) is the set of parameters in which the unique equilibrium is standardizing on technology A (B) after experimentation, whereas E_{α} (E_{β}) is the set of parameters in which the socially optimal outcome is standardizing on A (B). Note that $\mathrm{E}_{\alpha} \subseteq E_{\alpha}$, and $\mathrm{E}_{\beta} \subseteq E_{\beta}$, which implies that there is too little standardization *ex post* compared to the social optimum. The complement of a set E with respect to the space Ω will be denoted by E^c.

We consider two cases according to the relative magnitude of the parameter values of Δ and s.

<u>Case I: $\Delta < s$.</u>

Let us denote the complement of a set E with respect to the space Ω by E^c. Taking the equilibrium behavior in the second period into account, we can write the expected value of experimentation for individual 1 as follows:

$$V_E = m + \delta \left[\int_{\mathrm{E}_{\alpha}} (\alpha + \Delta) dG(\alpha,\beta) + \int_{\mathrm{E}_{\beta}} (\beta + \Delta - s) dG(\alpha,\beta) + \int_{(\mathrm{E}_{\alpha} + \mathrm{E}_{\beta})^c} \alpha dG(\alpha,\beta) \right] \quad (2),$$

where $m = \int_{\Omega} \alpha \, dG(\alpha,\beta) = \int_{\Omega} \beta \, dG(\alpha,\beta)$.

Since the values of the two technologies, α and β, are assumed to be symmetrically distributed, the expected value of experimentation for user 2 will be the same. The aggregate welfare from the equilibrium outcome, (market-induced welfare, W_E), therefore is $2V_E$.

In contrast, if the second-period standardization decision is made in the *ex post* socially optimal way, the expected value of experimentation for each individual will be given by

$$V_E = m + \delta \left[\int_{E_\alpha} (\alpha + \Delta) dG(\alpha,\beta) + \int_{E_\beta} (\beta + \Delta - s) dG(\alpha,\beta) + \int_{(E_\alpha + E_\beta)^c} \alpha dG(\alpha,\beta) \right] \quad (3)$$

The aggregate welfare is $W_E = 2V_E$. Due to the inefficiency of the market outcome in the second period, the market induced social welfare is less than the level of social welfare when the *ex post* optimal rule is adopted in the second-period decision. The inefficiency loss in the *ex post* standardization game is given by

$$L = V_E - V_E = \int_{E_\alpha - E_\alpha} \Delta dG(\alpha,\beta) + \int_{E_\beta - E_\beta} (\beta + \Delta - s - \alpha) dG(\alpha,\beta) > 0 \quad (4)$$

since $E_\alpha \subseteq E_\alpha$ and $(\beta + \Delta - s - \alpha) \geq 0$ on $(E_\beta - E_\beta)$.

<u>Case II: $\Delta > s$.</u>

In this case, the value of experimentation depends on the assumption we make on equilibrium selection for the region of the multiple equilibria. For instance, if we assume that they use mixed strategies, in view of proposition 1, we can write the expected value of experimentation as

$$V_E = m + \delta \left[\int_{E_\alpha} (\alpha + \Delta) dG(\alpha,\beta) + \int_{E_\beta} (\beta + \Delta - s) dG(\alpha,\beta) + \int_{(E_\alpha + E_\beta)^c} \frac{(\alpha + \beta + \Delta - s)}{2} dG(\alpha,\beta) \right]$$

The expected value of experimentation under the first outcome is once again given by equation (3). However, with $\Delta > s$, the third term in the square bracket in (3) is zero; since switching by neither player can never be optimum when the value of network benefit is larger than the cost of unilateral switching, $(E_\alpha + E_\beta)^c$ is an empty event.

In contrast, if we assume that they can coordinate on the pure strategy equilibrium that selects the superior technology, then there will be no inefficiency and $V_E = V_E$ and $W_E = W_E$.

2.2. Ex Ante Standardization

Now suppose that the two parties agree to standardize on one of the two technologies, say A, without loss of generality. With assumption (1), we can write the expected value of standardization as

$$V_S = (1 + \delta)(m + \Delta) \quad (5)$$

When there is early standardization, there is no decision to be made in the second period and there is no conflict between social planner and equilibrium outcome. The social value of standardization is $W_S = 2V_S = 2(1 + \delta)(m + \Delta)$.

2.3. Ex Ante Standardization vs. Experiment

When the potential users of the technologies decide which route to take for standardization, they will compare V_E and V_S. However, for the social planner who controls the *ex post* standardization process, the criterion will be the comparison between V_E and V_S. Due to the inefficiencies in the market process of *ex post* standardization we identified in proposition 2, we can have situations where $V_E < V_S < \bar{V}_E$. In that case, the first-best outcome dictates the adoption of experimentation, while the equilibrium chooses *ex ante* standardization since participants foresee the market inefficiencies in the *ex post* standardization process. Therefore, we have the following proposition.

Proposition 3. There is too much *ex ante* standardization compared with the social optimum.

Propositions 2 and 3 make it clear that a distinction must be made between two types of standardization processes. When there is no standardized technology, especially in the early stages of a technological cycle or in a nascent industry, it should not be viewed as a failure in the standardization process. It can be a deliberate and consensus choice by potential users. By the same token, if we see standardization of technology early on, it should not be viewed as a success or the first-best outcome. The reason why early standardization has been chosen may not be that it was the first-best option but that market inefficiencies were predicted in the *ex post* standardization process; a standard was agreed on too hastily for fear of each party getting entrenched too deeply in his experimental technology.

Our analysis also calls for caution in the judgement on the *ex post* standardization process. Even though there is too little *ex post* standardization, there are also cases where nonstandardization is *ex post* optimal since two experimented technologies turned out to be not so different in their values; switching costs do not justify the standardization.[17] Of course, these circumstances are exactly the ones for which experimentation is of lesser value. Consequently, a decision to experiment can be considered to be a mistake. However, we should be careful not to be trapped in this kind of *ex post* judgement, especially when we do specific industry case studies. The right criterion should be based on information available at the time of decision-making rather than information after experimentation. In this regard, *ex ante* standardization is immune to criticism when the actual use of technologies is essential for evaluation; the values of nonexperimented technologies will never be known precisely.[18]

The next step is the comparative statics inquiring what the properties of V_E and V_S are in order to determine the relative merits of experimentation vis-a-vis *ex ante* standardization. To facilitate the comparative statics analysis, in the remainder of the paper we focus only on the inefficiencies identified in Case I ($\Delta < s$). The possible inefficiencies in Case II ($\Delta > s$) are ignored since we do not have a good theory for selecting an equilibrium when there are multiple equilibria.[19]

[17]In contrast, Farrell and Saloner (1988) analyze the case where the outcome of standardization is always superior to that of nonstandardization.

[18]This may explain why standardization is usually associated with success, since there is no information available to conduct counterfactual inquiries.

[19]However, we may justify our approach in the following way. Suppose that the participants can communicate before experimentation in the first period, about how to play the game in situations of multiple equilibria. Then, they will decide to adopt the socially optimal rule. When an actual situation occurs in which the game can be played no player has an incentive to deviate. It should be noted that the first kind of inefficiencies cannot be eliminated by the nonbinding prior communications since it is not *ex post* incentive

Let $\Phi = V_E - V_S$. Then,

$$\Phi = -\Delta + \delta \left[\int_{E_\beta} (\beta - \alpha - s)\, dG(\alpha,\beta) - \int_{(E_\alpha + E_\beta)^c} \Delta dG(\alpha,\beta) \right] \tag{6}$$

The first term is an unambiguous loss of compatibility benefit in the first period due to experimentation with incompatible technologies. The terms in the square bracket are the potential benefit of experimentation in the future. Since the benefit of experimentation is realized in the future, it is clear that if the future is heavily discounted, experimentation is never worthwhile. The first term is increase in the payoff by switching to the other technology when it turns out to be much superior (i.e., in the event of E_β). The second term is loss of compatibility benefit when the *ex post* standardization is not realized. The failure occurs when the two values turn out to be similar (i.e., in the event of $[E_\alpha + E_\beta]^c$).

Inspection of equation (6) enables us to derive the following properties: The option of experimentation is more attractive as the compatibility benefit (Δ) and the switching cost (s) is lower. A necessary condition for there to be experimentation is that the sign of the expression in the square bracket be positive. In that case, experimentation is more valuable if the future is more important. I also expect experimentation to be a better option if the values of the two technologies tend to be negatively correlated. Then, the probability of event $[E_\alpha + E_\beta]^c$ occurring will be smaller and the first term in the square bracket will get larger. This intuition is confirmed in the next section for the two point distributions case.

I can also extend our analysis to allow for the first mover advantage in the adoption of technologies. Suppose that there is a first mover advantage in the sense that if the same technology is chosen but at different times by different users, then the early adopter receives a higher payoff than the late adopter. I can represent this strategic asymmetry by

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compatible. We may also justify our approach by appealing to the notion that standardization on the superior technology is more focal.

assuming that the first mover gets a higher proportion of compatibility benefits; the first mover gets $(1+k)\,\Delta$ and the second mover gets $(1-k)\,\Delta$. Then, when there is experimentation, each player has the same chance of being leader as he has of being follower. Therefore, as long as the probability of de facto standardization is the same as before, the first mover advantage will have no effect on V_E. However, the chance of reaching a standard is smaller due to the strategic advantage enjoyed by the first mover. This formalizes the idea that standardization is harder to achieve if the standard is not competitively neutral and relative positions of the users are asymmetrically affected [Gabel (1991)]. As a result, the first-mover advantage will make *ex ante* standardization more attractive.

3. Two Point Distributions Example and Correlation

To further analyze the properties of Φ, I confine ourselves in this section to the two point distributions for each technology. Suppose that each technology can have one of two possible values, v_H and v_L. Let the unconditional probability of each event be equal for both technologies, i.e., $P_i(v_H) = P_i(v_L) = 1/2$, where i=A, B. I allow for the realizations of values for each technology to be correlated to investigate the effect of correlation on the incentive to experiment. Since the experiment is more valuable when the two technologies tend to have different values, I expect that the more positively correlated the two technologies are, the less incentive there will be to experiment. I will confirm our intuition in the two point distribution example below.

There are four possible outcomes: (v_H, v_H), (v_H, v_L), (v_L, v_H), and (v_L, v_L). Let ρ be the correlation coefficient between the two technologies A and B. The probabilities for each event can be derived in the following way.

Let $\theta = v_H - m = m - v_L$. Then, $Var(\alpha) = Var(\beta) = \theta^2$, and $Cov(\alpha,\beta) = [P(v_H, v_H) + P(v_L, v_L) - P(v_H, v_L) - P(v_L, v_H)]\theta^2$, which implies that

$$\rho = [P(v_H, v_H) + P(v_L, v_L) - P(v_H, v_L) - P(v_L, v_H)] \qquad (7)$$

I also know that $P(v_H, v_H) + P(v_L, v_L) + P(v_H, v_L) + P(v_L, v_H) = 1$. Use of symmetry, i.e., $P(v_H, v_H) = P(v_L, v_L)$ and $P(v_H, v_L) = P(v_L, v_H)$, gives us the probabilities for each possible outcome:

$$P(v_H, v_H) = P(v_L, v_L) = \frac{1+\rho}{4} \quad \text{and } P(v_H, v_L) = P(v_L, v_H) = \frac{1-\rho}{4} \tag{8}$$

The value of experimentation can be written as follows:

$$V_E = \frac{1+\rho}{4} v_H (1+\delta) + \frac{1+\rho}{4} v_L (1+\delta) + \frac{1-\rho}{4} [v_H + \delta(v_H + \Delta)] + \frac{1-\rho}{4} [v_L + \delta(v_H + \Delta - s)]$$

$$= m (1+\delta) + \delta [\frac{1-\rho}{4} (v_H - v_L - s) + \frac{1-\rho}{2} \Delta] \tag{9}$$

Once again I assume that s is sufficiently large to satisfy condition (1).[20] Then, the value of *ex ante* standardization is as before:

$$V_S = (m+\Delta)(1+\delta) \tag{10}$$

The difference between the two approaches to standardization is :

$$\Phi = V_E - V_S = [- \Delta - \delta \frac{1+\rho}{2} \Delta] + \delta \frac{1-\rho}{4} (v_H - v_L - s) \tag{11}$$

The terms in the square bracket are the loss from experimentation; they lose compatibility benefit of Δ in the first period and lose again in the second period if the *ex post* standardization fails which occurs with probability of $\frac{1+\rho}{2}$ in the two point distribution case. The last term is the potential benefit from experimentation. If the experimented technology has a lower value of v_L and the other technology is revealed to have a higher value, v_H , there can be potential gain of $(v_H - v_L - s)$ which occurs with probability of $\frac{1-\rho}{4}$.

From equation (7), we can easily see that the value of experimentation relative to *ex ante* standardization increases as the correlation coefficient gets smaller and smaller, confirming our intuition. We can also analyze the effect of mean preserving spread on Φ. Let $\theta = v_H - m = m - v_L$. Then, the increase in θ can be thought of as a parameter

[20]Since $P(v_H \mid v_L) = \frac{P(v_H, v_L)}{P(v_L)} = \frac{1-\rho}{2}$, the assumption of no standard reversal in the second period can be written as $\frac{1-\rho}{2} (v_H - v_L) < s$.

representing the mean preserving spread in the distribution of each technology [Rothschild and Stiglitz (1970)]. Since the gap between v_H and v_L increases with θ ($v_H - v_L = 2\theta$), Φ is an increasing function of θ. Increases in the riskiness of technologies enhance the value of experimentation.

4. Concluding Remarks

I have presented a simple model to analyze the tradeoff between (*ex ante*) standardization and experimentation. In the process I proposed a new taxonomy for the standardization process: *ex ante* vs. *ex post*. In this paper, I look at the initial stage of incompatibility not as a coordination failure or the result of the vested interests of the parties concerned, but as a concerted effort to experiment with diverse technologies to extract information about the true values of the potential technologies. Experimentation, however, creates divergent preferences for each party, which leads to *ex post* standardization being realized less frequently than the social optimum. The consequence of this result is that the two parties will agree on early standardization too frequently if they foresee the inefficiency in the *ex post* standardization process.

Our model is very stylized and can be extended in several additional ways. First, I assumed that there was no ongoing uncertainty about the values of technologies. Moreover, one experiment was sufficient to resolve all uncertainty. If the values of the technologies are revealed over time or experiments generate only garbled information about the true values, then the experimentation process will be an optimal stopping problem: then, another decision variable is *when* to stop the experimentation process and standardize.

Second, the values of technologies can change over time especially if the values depend on the availability of complementary goods or there is a learning effect. Moreover, all potential technologies may not be ready for adoption at the same time. Then, users can lock themselves out of a superior technology by the time it is available.[21] In this case, the waiting option should also be explicitly analyzed. Similarly, users can be asymmetric in terms of their arrival time. Then, the adoption decision should be modelled as a sequential one [see Choi (1994b)].

Third, to facilitate the analysis the two potential technologies were assumed to be equally attractive *ex ante*. If they are not symmetrically distributed, the matching process between the users and the technologies may not be such a harmonious one if they choose to experiment. For instance, I can imagine that there is a very risky technology with a low mean. Since this technology may turn out to be extremely valuable, experimentation is worthwhile collectively. However, no one wants to experiment with this technology owing to its low expected value [Choi (1993b)].

Finally, I assumed that *ex ante* standardization setting entails no extra cost. However, a standard setting does entail cost. If there are many users who can potentially use standards without paying for them, there may be a significant free rider problem in creating standards [see Gabel (1991)]. This externality can create a bias against *ex ante* standardization in favor of experiment.

[21] David (1985) provides a fascinating account of this lock-in effect for QWERTY typewriters.

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Figures for "Standardization and Experimentation: *Ex Ante* vs. *Ex Post* Standardization"

by Jay Pil Choi

		Player 2	
		Switch	No Switch
Player 1	Switch	β - s, α -s	$\beta + \Delta$ - s, $\beta + \Delta$
	No Switch	$\alpha + \Delta$, $\alpha + \Delta$ -s	α , β

Figure 1. Payoff Matrix for Ex Post Standardization Game

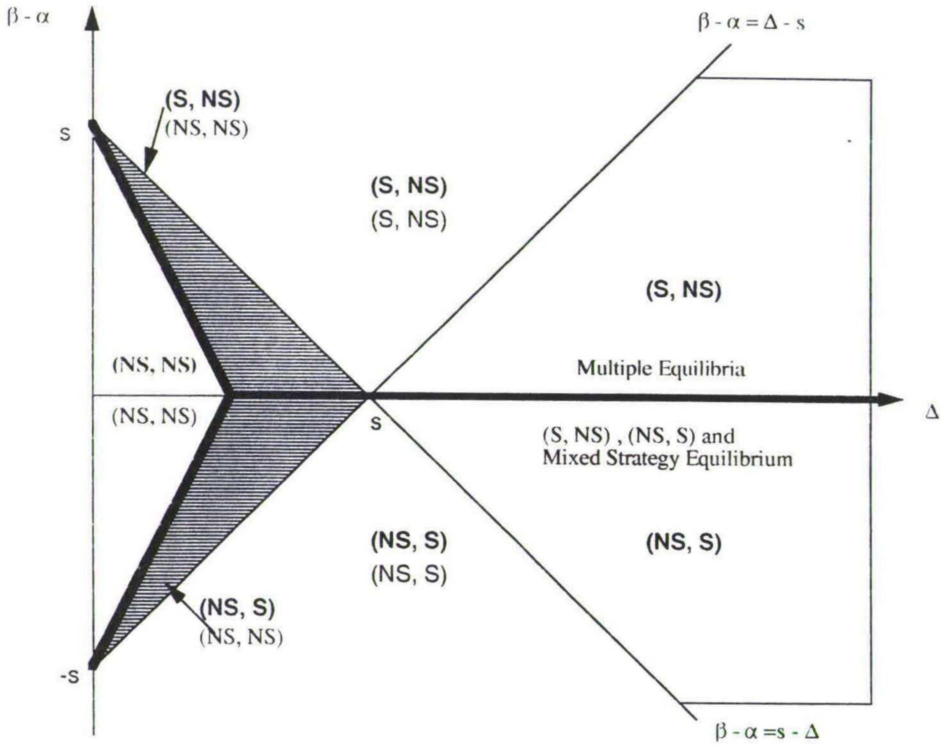

Figure 2. Equilibrium vs. Optimum. The plain characters describe the market outcomes, with the regions divided by thin lines. Socially optimal outcomes are described by the boldface characters and thick lines.

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