Choosing the Rules for Formal Standardization *

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Abstract

Consensus standardization—explicit agreement on compatibility standards—is marred by severe delays. We explore tradeoffs between speed and the quality of outcomes in a private-information model of the war of attrition. In this model, the consensus process can be excessively slow—even on an optimistic view of its quality-selection merits. However, we find that adding "vendor neutral" players can mitigate the tradeoff between screening and delay. We also show that intellectual property policies designed to reduce vested interest, and hence delays, do not necessarily weaken the players' incentive to innovate.

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1 Introduction

Compatibility standards often develop through explicit consensus. When participants have little vested interest in particular outcomes, the process will involve participants working together toward the best technical solution. If anything, there might be a free-rider problem, as standards development is a public good. But participants often do have strong vested interests, and while this helps overcome the free-rider problem, it can also make consensus hard to reach, as each participant holds out for agreement on its preferred standard.

Farrell and Saloner (1988) modeled such disagreement in consensus standard-setting using a complete-information war-of-attrition model. Their analysis predicted that consensus standardization is more likely to achieve coordination on a standard than is a *de facto* bandwagon race, but that (on average) it is slow.

This paper uses an incomplete-information war-of-attrition model to assess the performance of consensus standards development. The model predicts delays that are often long enough to make the process perform poorly, even on an optimistic view of its quality-selection merits. Specifically, we show that it can be efficient to cut short the screening process, and even an immediate random choice may well outperform the war of attrition, given the contending proposals. Policies that reduce vested interest can also help; in particular, private intellectual-property policies and related public policy can speed the process and need not weaken incentives to innovate. On the other hand, some administrative policies aimed at reducing delays do not address the rent-seeking problems that we stress.

1.1 The Formal Standards Process: Description and Delays

Standard setting organizations (SSOs) try to replace (or complement) the bandwagon *de facto* standards process with an orderly explicit search for consensus.[1] This process mingles technical discussion and political negotiation, in contrast to the race for market share and battle for expectations typical of *de facto* standardization.

Active participants incur substantial time and travel costs.[2] Weiss and Toyofuku (1993) stressed

[1]SSOs include both formally accredited standards-developing organizations (SDOs) and less formal standards forums and industry consortia. Cargill (1997) describes the standard setting process.

[2]Estimates of the direct pecuniary costs of formal standards activities vary widely. Siegel (2002, page 227) suggests that "a medium to large end-user corporation will invest $50,000 per year" in salary, travel, and membership fees to participate in one SSO — but also suggests that firms wishing to "contribute" technology may spend considerably more. Swann (1990, page 472) quotes estimates of 0.5%, 1%, and 2.5% of total revenues for IT and telecommunications firms. Much of the expense comes from participating in a large number of organizations. Updegrove (2003) reports

the resulting incentives for free-riding. Incentives to participate are provided by vested interests in particular solutions, but, as we study below, those vested interests hinder the consensus process.[3]

Vested interests in formal standard setting commonly arise from intellectual property rights or installed base. Brim (2004) claims that "the majority of the useful technologies brought to the IETF have some sort of [intellectual property] claim associated with them." And Kolodziej (1988) quotes an IEEE standards committee member as saying that "when there is 'silicon', or component products, already available in the market, it will always cause problems in standards work."

In principle, a standards organization could choose any decision mechanism, taking into account parties' information, their incentives to participate, and the need to produce standards that will attract widespread support (most consensus standards are voluntary). But standards organizations normally try to avoid compulsion and strongly seek "consensus," in part because of antitrust concerns.[4] Consensus need not mean unanimity, but for instance the International Organization for Standardization (ISO) defines it as:

> "general agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments." (ISO/IEC *Directives* 2004, page 26)

Similarly, the American National Standards Institute (ANSI)'s *Due Process Requirements for American National Standards* indicate that consensus implies:

> "substantial agreement has been reached by directly and materially affected interests. This signifies the concurrence of more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that an effort be made toward their resolution." (ANSI 2006, Annex A)

As a result, interested parties can often block or at least delay adoption of a standard they dislike. Following Farrell and Saloner (1988) we consider the case where two parties with effective veto power

that both Sun Microsystems and Hewlett Packard are members in more than 150 SSOs.

[3] At one point in 1988, *all* participants in the IEEE 802.3 work group represented companies with vested product interests. The chairman remarked, "We [the IEEE] don't have any organizational policies that bar individual users from attending and participating in these standards meetings. There are just not enough users who want to attend." See "Users cry for standards but don't get involved," *Computerworld*, May 4, 1988.

[4] The Standards Development Organization Advancement Act of 2004 (H.R. 1086) addressed some antitrust concerns by extending to SDOs protections in the National Cooperative Research and Production Act of 1993: making registered SDOs subject to the rule of reason standard in any antitrust action, and limiting liability to actual rather than treble damages. Nevertheless, SDOs have been reluctant to allow explicit licensing negotiations within the standard setting process—often citing fears of (perhaps baseless) antitrust lawsuits. Recently, antitrust agencies have sought to assuage such concerns: see e.g. Majoras (2005) or the discussion in the FTC's unanimous Rambus opinion (FTC 2006, page 36). On antitrust and standardization generally, see the American Bar Association *Handbook on the Antitrust Aspects of Standard Setting* (ABA 2004), or the FTC/DOJ Intellectual Property and Antitrust hearing transcripts and report (FTC 2002).

want a common standard but differ on their preferred proposals. This turns the standard setting process into a war of attrition.

1.2 Delays in Formal Standardization

If formal standard setting is a war of attrition, we can expect delays in reaching consensus. Indeed, formal standardization is notoriously slow, and participants often complain about delays. In a National Research Council survey (1990, page 21) the most common complaint was "the adoption process is too slow." Similarly, Sun Microsystems' head of standards stated:

> "[The] formal process — with its Byzantine structures, considerable delays for reconsideration, and re-vote — is... where the real and significant expense (as opposed to cost) of standardization occurs. If a company wants to bring a technology to market, and wants to make that technology common, the formal process can take up to 48 months to complete, resulting in lost market opportunity." (Carl Cargill, testimony before the Science Committee of the U.S. House of Representatives, 2001, page 11)

Some older SDOs have used the Internet to cut administrative delays. For example, in 1999 the International Electrotechnical Commission (IEC) reported that 20 percent of its standards were developed in less than three years, "in direct response to industry requests that we speed up the standardization process."[5] Still, even the fastest SSOs take several years to produce a significant standard. Our analysis suggests that these delays are not merely bureaucratic but (at least partly) caused by underlying vested interest, and initiatives that fail to address this problem can have only a limited impact on the time needed to reach consensus.

1.3 Related Literature

There is a relatively small economics literature on formal standard setting. Farrell and Saloner (1988) offered the first model of standard setting as a war of attrition. We introduce private information into that model, enabling us to evaluate the process in terms of how well it selects for the technically best proposal. Bulow and Klemperer (1999) and Myatt (2005) use standard-setting as a motivating example of the war of attrition.[6]

[5]By comparison, the IEC's 1991 *Annual Report* indicated a mean development time of 87 months (page 6), and the average development time for ISO standards between 1987 and 1991 ranged from six years to well over seven.

[6]These papers are also related to work on bargaining that studies subgame-perfect equilibria with delayed agreement. In addition to time-based signalling, as in the war of attrition, delays can occur in an alternating-offers bargaining equilibrium when there are more than three players (Shaked 1987), when disagreement payoffs are endogenous (Fernandez and Glazer 1991; Busch and Wen 1995), when there are externalities (Jehiel and Moldovanu 1995), or when the size of the pie is stochastic (Merlo and Wilson 1995).

Weiss and Sirbu (1990) were the first to collect data on SSO decision-making, which they used to study the determinants of successful proposals. Chiao, Lerner and Tirole (2006) examine SSOs' choice of procedures, and find evidence consistent with the model of "forum shopping" developed by Lerner and Tirole (2004), in which SSOs differ in their degree of sympathy for technology vendors (relative to end-users), and firms choose the friendliest SSO subject to the adoption constraint that certification will persuade end-users to adopt the standard. Rysman and Simcoe (2006), using patent citations, show that SSO endorsements increase the economic and technological significance of a standardized technology: patents disclosed in the standard setting process receive more citations at later ages, reflecting a substantial increase in the citation rate following disclosure. Finally, in a paper closely related to this one, Simcoe (2006) finds that while the Internet Engineering Task Force (IETF) is relatively fast (taking between one and two years to produce a new specification), several proxies for vested interest (based on committee demographics and intellectual-property ownership) are correlated with slower committee decision-making.

Our paper proceeds as follows. Section 2 develops a simple model of a two-player private-information war of attrition, in which each player's type is the quality of the technology that it proposes as a standard. A player's proposal is adopted when the other "concedes," and each player's payoff at that time depends on the quality of the proposal adopted and on who "won." We show that in the symmetric equilibrium the better proposal wins. Section 3 assesses the performance of this symmetric equilibrium, taking account of its selection of the better proposal and of its delays. In a simple example, we find conditions for this equilibrium to outperform immediate random choice, which can be viewed either as a metaphor for a faster, less careful process, or as the process when there is a predetermined dominant standard-setter. We also show that adding super-majority voting and neutral third parties to the war of attrition can usefully yield intermediate mechanisms with faster resolution but weaker screening. (In an Appendix, we discuss some other policies aimed at reducing delays, such as meeting more often, starting early, or adopting incomplete standards.)

In section 4, we ask whether reducing vested interest through intellectual-property disclosure and licensing policies might weaken incentives to develop better proposals. We show that the countervailing effect of faster adoption can outweigh the obvious adverse effect, so weaker intellectual property protection may actually increase incentives to innovate in a consensus standards context. In section 5, we address the concern that users are under-represented because their interests are diffuse. We ask how their *ex ante* preferences are likely to differ from active participants' (mostly vendors'). Section 6 concludes.

2 A Model

Two proponents offer systems, which may differ in quality: each player $i = 1, 2$ has a privately known quality q_i. They must choose a standard: the game ends when one player concedes, agreeing to use the other's proposal. (We assume there is no scope for compromise; side payments could raise antitrust concerns.)

Each player's strategy is a concession time t_i: player i concedes at t_i if the other has not yet conceded. If $t_1 < t_2$ then player 1 concedes at time t_1, and as of that date gets a payoff of Lq_2, while player 2 gets Wq_2. Here, $L > 0$ and $W > 0$ measure the "loser's" and "winner's" shares of surplus q. If $L = W$ then both players want the player with lower quality to concede. More realistically, as we assume henceforth, $W > L$: there is "vested interest." Thus, each player would like its proposal adopted, even if its rival has a somewhat higher quality (although each would want to concede if it *knew* that a rival's proposal were sufficiently better).

The players share a discount rate r, and flow payoffs are zero until agreement is reached.[7] That is, the market waits until there is a standard.

We consider a symmetric model, and focus on symmetric perfect Bayesian equilibrium: a concession-time strategy $t(\cdot)$, such that for a player of type q it is optimal to concede at time $t(q)$ if its rival has not yet conceded and if it believes its rival is also using the strategy $t(\cdot)$.[8]

2.1 Screening For Quality

Propositions 1 and 2 show that in the symmetric perfect Bayesian equilibrium, the better system wins.

Proposition 1 *Every rationalizable Bayesian strategy is weakly increasing: lower quality types concede before higher quality types.*

[7] Bulow and Klemperer (1999) examine the N-player symmetric war of attrition. In their model, when a participant's flow costs do not depend on whether it has already conceded — a case they call the "standards version" of the game — the war of attrition is equivalent to an all-pay auction, and the players' strategies are independent of the number of participants. Alternatively, when participation costs are large relative to the costs of delay (i.e. when flow costs drop to zero upon concession), all but two players concede *instantly*. In these extreme cases, the length of the game depends only on the second-best proposal's quality, just as in a two-player war of attrition; the *ex ante* expected duration increases with the number of players since it depends on that second-order statistic.

[8] In general, this might be a mixed strategy, but it will not be in the examples we consider.

Proof: See Appendix.

In the war of attrition, the winner is the player with the later concession time. By Proposition 1, in the symmetric equilibrium this is the player with the higher-quality proposal.

Proposition 2 *In the symmetric equilibrium of the war of attrition, each player's strategy implies a continuous and gap-free distribution of concession time. Consequently, the winner is the higher-quality system.*

Proof: See Appendix.

This sorting or discrimination property is well known (e.g. Bliss and Nalebuff, 1984). Below, we consider whether the war of attrition buys this sorting at too high a price in delay. Here, we pause for two comments.

First, in general the war of attrition selects for willingness to wait. In our simple model, differences in willingness to wait are caused solely by differences in quality, so that selection is ideal. This clearly overstates the case. Katz and Shapiro (1985) emphasized that small firms often are keener to have a standard than are large firms: so the war of attrition may favor large firms' proposals. Also, firms whose only interest in the process is their intellectual property may be very reluctant to concede.

Second, Proposition 2 concerns the symmetric equilibrium. There is often also an asymmetric equilibrium in which player 1 never concedes and player 2 concedes immediately,[9] as well as the mirror-image equilibrium. In *ex ante* symmetric situations, the symmetric equilibrium seems a natural model, but if one player is seen as a focal standard-setter, the asymmetric equilibrium may well be played. Historically, IBM may have been focal in the computer industry, and AT&T in US telecommunications.[10]

2.2 Properties of Equilibrium for Continuous Distributions

Suppose that quality q is distributed independently for each firm with the continuous distribution function $F(\cdot)$. Define

$$G(q) \equiv \mathrm{E}[y|y > q] = [1 - F(q)]^{-1} \int_q^\infty \mathrm{d}F(y)$$

[9] This must be supported by out-of-equilibrium beliefs of the same form: if player 2 does not immediately concede, player 1 must expect that it will do so at the next instant. There must also be enough vested interest so that if player 1 knows its quality is extremely low it will still prefer to let player 2 concede.

[10] The Telecommunications Act of 1996 in the US requires certain forms of fair behavior by Bell companies in standard setting.

and observe that

$$G'(q) \equiv h(q)[G(q) - q] \tag{1}$$

where h denotes the hazard rate $h(q) \equiv f(q)[1 - F(q)]^{-1}$.

Now consider the problem facing a player of type q who, according to the equilibrium, is meant to concede at time $t(q)$. Once that time is reached, conceding yields an expected payoff of $LG(q)$. Holding out a short time $\mathrm{d}t$ longer yields an expected payoff of

$$[h(q)q'(t)\,\mathrm{d}t]\,Wq + e^{-r\,\mathrm{d}t}\,[1 - h(q)q'(t)\,\mathrm{d}t]\,LG(q + q'(t)\,\mathrm{d}t)$$

where the function $q(\cdot)$ tells us what type is meant to be conceding at any instant — it is the inverse function of the $t(\cdot)$ function. Hence (suppressing arguments for brevity)

$$0 = hq'Wq + LG'q' - hq'LG - rLG$$

or, after rearranging terms

$$0 = L(G'q' - rG) + hq'(Wq - LG) \tag{2}$$

Each participant has two reasons to delay: screening and rent-seeking. The first term in (2) is the screening incentive, which reflects a trade-off between the increase in expected payoff following concession ($G'q'$) and the opportunity costs of delay (rG). This is the same trade-off faced by an end-user who values quality but does not observe the players' private information. Thus, screening is locally efficient (i.e. worth its delay cost) whenever this term is positive. The second term in (2) is the rent-seeking incentive, which depends on the equilibrium concession rate (hq') and the expected rents from winning ($Wq - LG$). This term captures the inefficiency introduced by vested interest.

Since (2) is the players' first-order condition, the screening and rent-seeking incentives must cancel one another for a player who is indifferent between concession and screening for an additional instant. Thus, whenever screening is locally efficient, the marginal player's expected payoff from concession exceeds the actual benefit of an immediate win. Put differently, if $q_1 \approx q_2$ and screening benefits are larger than delay costs at $t(q)$, then winning is "bad news" because the loser's quality is considerably worse than expected.

Lemma 1 *In a symmetric equilibrium, the marginal type prefers concession to immediate victory if and only if screening is locally efficient:* $G'q' > rG \Leftrightarrow Wq < LG$.

Proof: Fix t and consider the marginal player with type $q(t)$. The first-order condition (2) implies that if $G'q' > rG$ then $Wq < LG$, since the two terms must have opposite signs. Q.E.D.

To find the players' equilibrium concession strategy, substitute (1) into (2). This yields

$$0 = [W - L]hqq' - rLG$$

Defining $v \equiv (W - L)/L \geq 0$, we can separate the previous equation to get

$$r\,\mathrm{d}t = \frac{vqh(q)}{G(q)}\,\mathrm{d}q \tag{3}$$

This differential equation, together with the boundary condition $t(q_{min}) = 0$, defines the symmetric Bayesian equilibrium. To solve for $t(q)$, we define $K(q) \equiv \int_q^\infty y\,\mathrm{d}F(y)$, and note that $K(q_{min}) = \mu$, the mean proposal quality. Moreover, we have

$$\frac{-\,\mathrm{d}\log K(q)}{\mathrm{d}q} = \frac{qf(q)}{K(q)} = \frac{qh(q)}{G(q)}$$

So, the solution to (3) is

$$rt = v\log\mu - v\log K(q)$$

or in terms of the time value of delay until q concedes,

$$\delta(q) \equiv e^{-rt(q)} = \left[\frac{K(q)}{\mu}\right]^v \tag{4}$$

In (4) r has disappeared — it affects the time to agreement but not the payoffs.

Proposition 3 *The ex ante performance of the symmetric equilibrium of the war of attrition is independent of* r*. Delays are increasing in* v*. When* v *approaches zero (no vested interest), so do delays, and performance approaches first-best.*

3 Performance

In this section we evaluate the performance of the war of attrition. To do so, we ask what could be achieved by a highly constrained social planner who knows the game and parameters but not the proposal qualities, and whose only policy instrument is to choose how long (T) to let the war of attrition continue before intervening and picking a proposal at random.

One extreme special case is the war of attrition itself (never intervene, $T = \infty$); the opposite is immediate "random choice" (intervene immediately, $T = 0$). We show that each of these extreme choices of T can be optimal.

For $T \neq 0, \infty$, if the proponents were to anticipate the intervention, one would expect their concession strategies to change in response; as discussed below, their Bayesian strategies would in general become mixed, and we have been unable to analyze the consequences. We (temporarily) brazenly ignore this fact! This approach would make sense if intervention were completely unanticipated, but that is not our main justification. Rather, we justify the brazen approach by showing below—remarkably—that if the proponents anticipate that $T = t^*$, the *optimal* time for a surprise intervention, then it remains an equilibrium for them to play the same concession strategies as they would if they expected no intervention.

Thus, we analyze the choice of T under the generally false, but (we will show) true at $T = t^*$, assumption:

Assumption 1 *If the proponents expect a random choice at T, then their equilibrium concession strategies are unchanged.*

3.1 Performance and Random Intervention

Suppose that a random choice will be made (if no concession has yet occurred) at time T, and assume for now that the players' concession strategies are unaffected. Then *ex ante* expected welfare is

$$\hat{W}(T) \equiv \int_0^T e^{-rs} G(q(s)) f(q(s)) q'(s)\, \mathrm{d}s + e^{-rT} G(q(T))[1 - F(q(T))] \tag{5}$$

The value of screening a little longer is $\hat{W}'(T)$, which is proportional to

$$G'(q(T))q'(T) - rG(q(T)) \tag{6}$$

By Lemma 1, this expression is positive if and only if $Wq(T) < LG(q(T))$. A little more screening before random choice is desirable when

$$G(q(T)) - (1+v)q(T) > 0 \tag{7}$$

If (7) always holds, then (under Assumption 1) a constrained social planner will never want to intervene: the war of attrition screens efficiently enough that it is never worth randomly interrupting. If (7) never holds, a little delay is always undesirable, and the best the constrained planner can do is immediate random choice. Both of these extreme cases are possible, as the following example shows:

Proposition 4 *Suppose proposal quality has a Pareto distribution: $F(x) \equiv 1 - x^{-(1+a)}$ for $x \geq 1$ (where $a > 0$). Under Assumption 1, a constrained social planner prefers immediate random choice when $av > 1$ and screening via the war of attrition when $av < 1$.*

Proof: For this distribution $G(x) = \frac{(a+1)x}{a}$, so that $G(q) - q = q/a$. Thus, when $av < 1$, (7) holds for all q: additional screening always has positive expected value. Similarly, when $av > 1$, additional screening always has negative expected value. Q.E.D.

In general, there is no reason to expect that either (7) or the reverse will hold globally. For example, the war of attrition may outperform an immediate random choice even though screening is initially unattractive: (7) fails for low values of q but holds for higher values.

If (7) holds for small values of q, but not larger ones, then (still relying on Assumption 1) screening is initially worthwhile but later not. In particular, if $G(q) - (1+v)q$ crosses the axis exactly once (and from above), there is a unique q^* such that a constrained planner prefers the war of attrition until $T = t^* \equiv t(q^*)$ and immediate random choice thereafter.

Bagnoli and Bergstrom (2005, Theorem 6) prove that $G(q) - q$ is strictly decreasing when either the probability density $f(q)$ or the reliability function $1 - F(q)$ is log-concave: this condition holds for many commonly used probability distributions, including the uniform, normal, exponential and logistic.[11] Since vq is strictly increasing and has no upper bound, we have the following result.

Lemma 2 *Under Assumption 1, if $\mu > (1+v)q_{min}$ (screening is initially preferred) and either $f(q)$ or $1 - F(q)$ is log-concave, there is a unique time t^* such that a constrained social planner prefers screening via the war of attrition at all $t < t^*$ and immediate random choice thereafter.*

[11] The function $G(q) - q$ is the average quality difference between the marginal type and all higher types. In failure analysis, it is called the mean residual life function. When this function is decreasing, a machine "ages" in the sense that its expected time-to-failure declines over time.

As promised above, we now justify our reliance on Assumption 1, by showing that it is correct if players expect a random choice at $T = t^*$.

Proposition 5 *When $\mu > (1+v)q_{min}$ and either $f(q)$ or $1 - F(q)$ is log-concave, the following strategies are a perfect Bayesian equilibrium: For $t < t^*$, sponsors play the concession strategies derived in Section 2. Once $t \geq t^*$ sponsors never concede. The social planner does not act until t^*, but intercedes by making a random choice at all $t \geq t^*$.*

Proof: First, note that since (7) holds with equality at t^*, Lemma 1 implies that $Wq(t^*) = LG(q(t^*))$. In other words, the "last" vendor-type to concede before intervention is indifferent between winning and concession.

We need to show that two kinds of deviations are unrewarding for the players. First, in the candidate equilibrium, a player with type $q > q^*$ will wait until its rival concedes or the random choice is made; might this player deviate by conceding early, before t^*? Second, a player with type $q < q^*$ is meant to concede before the random choice at t^*; might it deviate by waiting till t^* and having a good chance of winning?

First, by Lemma 1, at t^* a player with $q > q^*$ prefers random choice to concession. Since the type q^* player at least weakly prefers concession at t^* to concession at any $t < t^*$, the same is true (see the proof of Proposition 1) of any higher type. (Alternatively, one can note that the first-order condition (2) implies that the marginal benefit of delay is increasing in q for all t; so any vendor who prefers a random choice at t^* cannot do better by deviating to $t < t^*$ (since this is worse than conceding at t^*).) This shows that these high types $q > q^*$ do not have an incentive to deviate from equilibrium play. We must also check that they would not deviate from the prescribed out-of-equilibrium play. That is, if at $t > t^*$ there has still been no random choice, but they expect one imminently, would a high-type player try to concede before that random choice? No: by Lemma 1, such a high type prefers random choice.[12]

Second, and perhaps more surprising: a "low quality" vendor with $q < q^*$ now expects, by waiting till t^*, to be able to get a fifty percent chance of winning. Might not that be a tempting deviation? No—by Lemma 1, for a low quality vendor, concession just before t^* dominates random choice

[12] This would break down if the player believes that types $t \in (q^*, Q)$ of his opponent would have already conceded by now (after t^*), so that concession looks better now, relative to random choice, because opponent's expected quality is now $G(Q) > G(q^*)$. But this is not an issue, since we are specifying that each believes that the other is playing "never concede after t^*, and there can be no evidence to falsify that belief: the only available evidence would be concession, after which the question doesn't arise.

at $t \geq t^*$: once as much selection has happened (on the opponent's side) as has (in equilibrium) happened by t^*, Lemma 1 tells us that a low-type player *no* longer wants to win.

Finally, consider the constrained social planner or neutral player. It might be conventional to give even a social planner some commitment power, but we want to be able to interpret the result as equilibrium play with an ordinary but disinterested participant and with the SSO rule that a standard can be adopted with a two-thirds majority. Thus we claim that the behavior described is equilibrium play for the neutral player. By the definition of t^*, this player prefers to allow screening at all $t < t^*$ but wants to intervene then. Since the out-of-equilibrium expectations are that no vendors will concede at any $t > t^*$, if no actual concession has happened by such a time, the same calculation says that the neutral player wants to intervene now. Of course, if actual concession has happened, there is no incentive question to resolve. Q.E.D.

We now offer several remarks about this equilibrium. First, the social planner's threat of intervention at all $t > t^*$ (i.e. off the equilibrium path) is credible even with "weaker" beliefs about the vendors' out-of-equilibrium strategies. For example, we originally motivated t^* by asking when a constrained planner would want to end a war of attrition that would otherwise continue indefinitely. (This would be the case, for example, if the vendors believed that intervention was a "one shot" opportunity available to the neutral player only at t^*; or that there is an "interventionist type" of neutral player who would intercede at t^*, so that a failure to intervene shows that the neutral player is not that type.)

Second, the comparative statics of this equilibrium are straightforward. From (7), an increase in v leads to a reduction in q^*. In other words, the social planner responds to increasing vested interest by giving up some screening benefits in favor of a more timely standard, thus shifting the equilibrium "towards" random choice.

Third, Fudenberg and Tirole (1986) also studied "finite selection" equilibria in the war of attrition — i.e. pure strategy equilibria where the screening process ends in finite time. Their Lemma 2.ii shows that in any such equilibrium, the last type to concede must be indifferent between concession and the outside option; in this case, a random choice.[13] Thus, when the social planner is expected to intervene at $T \neq t^*$, some vendors will respond by playing mixed strategies.[14] Since we have not been able

[13] Here is a sketch of the argument: Suppose the social planner is committed to intervening at T and q_h is the lowest upper-bound among the types that are willing to concede in equilibrium (i.e. all q such that $LG(q(T)) \geq Wq$). If $LG(q_h) > Wq_h$ (this player strictly prefers concession) then there is some type $q_h + \varepsilon$ that also prefers to concede, a contradiction.

[14] In other words, there is no solution to the differential equation (3) that satisfies both of the following boundary conditions: $t(q_{min}) = 0$ and $t(q^*) = T$ (where $T \neq t^*$).

to characterize these strategies, we do not know whether a constrained social planner might prefer to intervene earlier (though mixing clearly implies some welfare loss due to imperfect screening). So we do not know that intervening at t^* is the optimal strategy (if announced in advance) for a social planner, only that it is an option, is credible, and does not disturb the proponents' concession strategies, so that our analysis comparing it to the pure war of attrition and to immediate random choice was valid.

Institutionally, is this constrained social planner or neutral player a (simplified) reality or just an analytical fiction convenient for our analysis? Many SSOs encourage participation by "vendor neutral" third parties.[15] These players may be able to break a deadlock between proponents with vested interests — either informally, or through a formal vote if the SSO allows for super-majority voting.

It is tempting to think that recruiting and empowering vendor-neutral parties would be easy — in this model the neutral player need only wait a while and then toss a coin. In reality, one might seek to treat end users or complementors[16] as likely neutral participants, although both groups can have their own rent-seeking incentives: see Section 5. A second concern is that while random choice (or a move in that direction) looks good when the standards process is painfully slow, formalizing that decision rule might lead to an increase in the submission of low quality proposals.

3.2 Interim Performance and Participation

Once the sponsors of a proposal observe q, their preferences are no longer identical to the social planner's. In this sub-section, we compare the performance of an uninterrupted war of attrition to immediate random choice — taking the perspective of a player who knows their own proposal quality.

Write $u(q)$ for the expected payoff to a player of type q in the symmetric equilibrium. From the envelope theorem, $u'(q)$ is equal to the gain from an increase in q holding concession strategy fixed.

$$u'(q) = W \int_{q_{min}}^{q} \delta(y)\,\mathrm{d}F(y) = W \int_{q_{min}}^{q} \left[\frac{K(y)}{\mu}\right]^{v} \mathrm{d}F(y) \tag{8}$$

[15] For example, ANSI's Essential Requirements stress the need for a "balance of interests" defined as: "no single interest category constitutes a majority of the membership of a consensus body." ANSI's broad interest categories include producers, users (who are distinct from consumers) and general interest (e.g. individual or academic) members (ANSI 2006, page 6).

[16] Intel is involved in a broad range of standard-setting activities, even where it has little vested interest in a technology, because the standardized products complement its micro-processors.

Thus, a player's (interim) expected payoff in the war of attrition is an increasing and convex function of q. We can solve for $u(q)$ by integrating (8), or express it directly by accounting for the outcome as a function of the rival's type.[17]

$$u(q) = Wq \int_{q_{min}}^{q} \delta(y)\,\mathrm{d}F(y) + \delta(q)L \int_{q}^{\infty} y\,\mathrm{d}F(y) \tag{9}$$

We consider two interpretations of random choice. In the first instance, it represents a predetermined standard setter. In the second, it represents a "rough and ready" selection process (or a very fast and non-discriminating standards war). These interpretations differ for the players, but are equivalent in terms of welfare—in each case there is an immediate standard with expected quality μ.

When random choice represents a predetermined standard-setter, the standard-setter receives Wq while the other player's expected payoff is $L\mu$. The latter player's resistance to this mechanism clearly increases with the quality of its proposal (though it is not clear whether they have any incentive to develop such a proposal). It is perhaps more interesting to ask whether a predetermined standard setter would ever forfeit the privilege? The would only happen if $Wq < u(q)$. Substituting (9) into this inequality and rearranging terms reveals

$$Wq < \frac{\delta(q)LK(q)}{1 - \int_{q_{min}}^{q} \delta(t)\,\mathrm{d}F(t)} \leq \frac{\delta(q)LK(q)}{1 - F(q)} \leq LG(q)$$

Thus, by Lemma 1, a predetermined standard setter that favors "open" standard-setting must have $q < q^*$. Interestingly, this suggests there is no benefit from vendor-neutral participation when the consensus process is sponsored by a predetermined standard setter.[18]

Now consider the interpretation of random choice as a rough and ready selection process. From (8) we know that $u(q)$ is increasing and convex, while the expected payoff under random choice $\frac{1}{2}(Wq + L\mu)$ is linear in q. This leads to several possibilities.

If $L\mu > Wq_{min}$ (so immediate concession dominates random-choice for the lowest quality-type) either all players prefer the war of attrition, or preferences are non-monotonic: low and high quality-types prefer a war of attrition and those in the middle favor random choice. Intuitively, low types know that a war of attrition will deliver its expected screening benefits quickly, while high types have

[17] Combining (8) with the bottom boundary condition $u(q_{min}) = L\mu$ yields the following alternative expression $u(q) = L\mu + W \int_{q_{min}}^{q} \int_{q_{min}}^{z} \left[\frac{K(y)}{\mu}\right]^{v} \mathrm{d}F(y)\,\mathrm{d}z$

[18] Of course, we have not analyzed the welfare properties of any potential mixed strategy equilibria should the neutral player intervene before t^*.

a good chance of capturing the available rents.

On the other hand, if $L\mu < Wq_{min}$ either all players prefer a random choice, or low types favor random choice while high types favor a war of attrition. In this case, the rent seeking incentive dominates and (roughly speaking) players favor the mechanism that gives them a better chance of winning. The following proposition summarizes the players' interim preferences.

Proposition 6 *Interim preferences depend on q. A predetermined standard setter will only favor the war of attrition if $q < q^*$. When random choice represents a "rough and ready" decision-making process, the players' interim preferences may be non-monotonic in q.*

4 Vested Interest and the Incentive to Improve Standards

Most SSOs have rules concerning members' duties to search for, disclose, and license any proprietary technology that is part of a standard. Perhaps the most common policy is the "reasonable and non-discriminatory" or RAND licensing requirement.[19] Loosely, RAND policy requires a promise to license any essential technology liberally. For example, ANSI rules require that any patented technology used in a proposed standard be licensed either "without compensation" or "under reasonable terms and conditions that are demonstrably free of any unfair discrimination."[20]

A combination of imperfectly enforced licensing standards, loosely enforced disclosure requirements, and platform-specific investments has led to several high-profile disputes over intellectual property in consensus standards. Usually, it is alleged that some firm violated its SSO membership obligations when it used the formal standard setting process to create hold-up. For example, the (US) Federal Trade Commission has investigated both Dell (1995) and Rambus (2002) for attempting to license essential patents that were not disclosed in the standard setting process, and settled an analogous complaint against Unocal. A unanimous ruling by the FTC (2006) in the Rambus case suggests that antitrust authorities are willing to enforce the provisions and spirit of SSOs' IPR policies to prevent manipulation of the standard setting process in order to gain market power.

These cases, along with a substantial increase in IPR disclosure at many SSOs (see Simcoe 2006) have led to increased public policy interest in SSO IPR policies and may have prompted some SSOs

[19] Lemley (2002) and Chiao, Lerner and Tirole (2006) survey IPR policies; Teece and Sherry (2003) and Farrell, Hayes, Shapiro, and Sullivan (2007) discuss SSOs' IPR policies and antitrust.

[20] See the Appendix for a more detailed discussion of SSO intellectual property policies.

to explore stronger disclosure and licensing requirements.[21] Such policies will reduce v, and our model indicates that this will reduce delays. The obvious economic concern, which we address in this section, is whether these rules reduce the incentive to develop technology in the first place?

We begin with a simple example to show that reducing v need not reduce the participants' incentive to improve q. Next, we compare innovation incentives under the war of attrition and immediate random choice. Finally, we consider the negative externality produced by improvements to a losing proposal in the war of attrition. In particular, we show that a war of attrition can produce either "too much" or "too little" innovation from a social planner's perspective.

4.1 Incentives to Improve q

Equation (8), which gives $u'(q)$, tells us something about a firm's incentive to improve (the distribution of) the quality of its proposals. Assuming that a firm's rival cannot observe its quality improvements, the rival will continue to play the same concession strategy, and (8) offers a point-specific estimate of the gain from improving quality. This can be combined with the marginal effect on the distribution of q from some effort variable.

Thus, suppose that player 1 believes that its rival, player 2, has a distribution of q as given above, and that player 2 will play a concession strategy as if it believes that player 1 also has this distribution. Suppose however that player 1 chooses an effort variable e that affects the distribution of its quality q, which it (but not player 2) will observe before the war of attrition begins. Then the gross incentive to increase e is given by the change in its expected payoff,

$$\int_{q_{min}}^{\infty} u(q)\,\mathrm{d}F(q;e) = [u(q)F(q;e)]_{q_{min}}^{\infty} - \int_{q_{min}}^{\infty} F(q;e)u'(q)\,\mathrm{d}q,$$

and the first term on the right is independent of e provided that the support of q does not change; hence the gross incentive to increase e is

$$-\int_{q_{min}}^{\infty} \frac{\partial F(q;e)}{\partial e} u'(q)\,\mathrm{d}q.$$

Perhaps more intuitively, effort that shifts q up by $\mathrm{d}q$ whatever the realization of the random q will be worth $\mathrm{E}[u'(q)]\,\mathrm{d}q$. Thus we take $\mathrm{E}[u'(q)]$ as a measure of the *ex ante* incentive to improve quality.

[21] See for instance "Ex Ante Disclosure : Risks, Rewards, Process and Alternatives" *Consortium Standards Bulletin*, June 2006, www.consortiuminfo.org/bulletins/.

How do innovation incentives respond to changes in vested interest? In general, a change in either W or L will produce two effects: a shift in the marginal returns to q, and a change in the amount of time needed to achieve consensus. When $F(\cdot)$ has a Pareto distribution (as in the example of Proposition 4), the incentive to improve proposals is

$$I^{\mathrm{WOA}} \equiv \mathrm{E}[u'(q)] = \frac{W(a+1)}{av+2a+2} = \frac{LW(a+1)}{Wa+L(a+2)} \tag{10}$$

Differentiating this expression reveals that an increase in either W or L produces an increase in incentives. What happens if we hold the total surplus constant and focus on purely distributional changes? Normalizing $W + L = 1$, so $W = (v+1)/(v+2)$, and taking the derivative of (10) with respect to v reveals that

$$\frac{\mathrm{d}I^{\mathrm{WOA}}}{\mathrm{d}v} = \frac{(a+1)\left[2 - av(v+2)\right]}{\left[(v+2)(a(v+2)+2)\right]^2}$$

Thus, increasing v increases the mean incentive to improve q (i.e. $\mathrm{d}I/\mathrm{d}v > 0$) if and only if $va(v+2) < 2$: that is, when there is sufficient quality dispersion ($a < 1$) and v is relatively small. If increasing v raises innovation incentives, then the war of attrition outperforms random choice (by Proposition 4) since $av < 1$.

Proposition 7 *Intellectual-property rules that reduce vested interest need not reduce the participants' incentives to improve q.*

4.2 Relative Incentives

Consider the corresponding incentive to improve quality for a predetermined standard-setter. Since this player's payoff is just Wq, the incentive to improve quality is $I^{\mathrm{PS}} = W$. Our other interpretation of "random choice," as a rough-and-ready choice between systems once they are presented, gives each participant an incentive $I^{\mathrm{RC}} = \frac{1}{2}W$. However, this is still larger than incentives under the war of attrition.

Proposition 8 *A predetermined standard setter has largest incentive to innovate, followed by firms facing a symmetric random choice, and finally firms in a war of attrition.*

Proof: From (8), we have

$$I^{\mathrm{WOA}} = W \int_{q_{min}}^{\infty} \int_{q_{min}}^{x} \delta(y)\, \mathrm{d}F(y)\, \mathrm{d}F(x)$$

When $v = 0$, then $\delta(s) = 1$, so that

$$I_{v=0}^{\mathrm{WOA}} = W \int_{q_{min}}^{\infty} F(x)\, \mathrm{d}F(x) = \frac{1}{2} W$$

and since $\delta(s) < 1$ for all s when $v > 0$, we have

$$I^{\mathrm{PS}} = W > I^{\mathrm{RC}} = \frac{1}{2} W \geq I^{\mathrm{WOA}}$$

The first inequality states a well known result: stronger appropriability leads to more investment in innovation. The second inequality shows that innovation incentives are smaller under the war of attrition — delays reduce the players' payoffs without changing the expected allocation of the surplus. One might think this would be offset by rent-seeking "competition" in quality-levels, but this is not the case.

In fact, it is not clear that a consumer (or constrained social planner) would want the players in a war of attrition to have stronger innovation incentives. While third-parties would certainly like the winning proposal to have a larger q, improvements in the quality of the losing proposal lead to longer delays. When this negative externality is large, the war of attrition might encourage too much innovation.

Given that a standard will be chosen by the war of attrition, when will the welfare effects of increasing q be negative? The expected surplus of a proposal with quality q depends on the (unknown) quality of its rival. We can write the total (interim) expected surplus as

$$s(q) = q \int_{q_{min}}^{q} \delta(y)\, \mathrm{d}F(y) + \delta(q) \int_{q}^{\infty} y\, \mathrm{d}F(y)$$

Differentiating this expression leads to a point-specific measure of the welfare impact from quality improvements.

$$s'(q) = \int_{q_{min}}^{q} \delta(t)\, \mathrm{d}F(t) - vq\delta(q)f(q)$$

When v is small, the first term dominates and the incentives provided by a war of attrition are "too weak" from a social planner's perspective. This is the standard free-riding result. However, as v grows large the negative externality captured by the second term becomes more important, and the incentives produced by a war of attrition may become "too strong."[22]

Proposition 9 *Innovation incentives under the war of attrition can be either too strong or too weak from the perspective of a constrained social planner.*

5 Non-Participants' Interests

Observers of formal standardization often fear that the interests of users, who typically do not themselves participate in the standards process, may be poorly served. In this section we use our modeling framework to discuss how users' and participants' interests may differ, and thus where we might be concerned about representation.

In very broad terms, provided that active participants indeed want a standard, they tend to have the same wish list as non-participants, who typically want a standard too. Users want the standard promptly; so — in this case — do vendors. Users want a high-quality standard; so, presumably, do vendors. However, users and vendors may have very different tradeoffs among these shared objectives. In our notation, participants' payoffs in aggregate are equal to $(W+L)qe^{-rt}$; nonparticipants' might be represented as $(1-W-L)f(q)e^{-rt}$, where the function $f(\cdot)$ might be nonlinear. Thus the two groups' incentives differ in several possible ways:

5.1 Direct Costs

In the model we have assumed that the cost of delay is primarily the delay in getting the benefits of a standard. In fact, participants bear the direct costs of the process and nonparticipants do not. This leads to several possible disagreements. First, there may be a public-good or free-rider problem: if participants' rents are too small, nobody may shoulder the costs of participating. Second, active participants will be biased against standardizing in advance, which increases direct costs because they are borne earlier and are often borne when delay might reveal that there will be no market. Third, if working faster has a greater flow cost, the model suggests that participants should be roughly indifferent to this (since it is screening that determines time to agreement), while nonparticipants

[22] For the Pareto distribution, calculations show that $E[u'(q)] > E[s'(q)]$ if and only if $v(v+1)(a+1)^2 > av+2a+2$.

will urge more speed.[23] This effect seems unlikely to be large, since direct costs are presumably small compared to foregone revenues from an important market. It is also worth noting that increasing the flow costs of participation will presumably drive out some marginal participants, leaving only those with the strongest vested interests; an effect analyzed by Turner and Weninger (2005).

5.2 Rent-Shifting

Participants want both W and L to be large, although they also care about the balance between them; nonparticipants (at least once the systems are developed) prefer both W and L to be small, as well as wanting v to be small (i.e. $W \approx L$).

How might participants design or influence the process so as to increase their joint rents $W + L$? They might set substantial license fees for the standard or for technology embodied in it. They might perhaps favor a technology that (given its quality) has a demand structure that lets an imperfectly competitive industry extract a relatively large fraction of the social surplus. They might use the standards process to exclude rent-destroying new technology. Many such actions, if jointly undertaken in order to increase joint rents, would presumably be antitrust violations. Since the standards community is generally apprehensive about antitrust, they will have some motive to steer clear of blatantly anti-competitive acts. But the distinction between technical necessity and rent-shifting can be subtle. For example, most cellular handsets use standardized "system operator codes" to determine whether they are eligible to use a particular carrier network. By "locking" these codes, the wireless carriers — who helped write the standards — can raise customers' switching costs by preventing the use of an otherwise compatible phone on another carrier's network.[24]

5.3 Value of Additional Quality

If $f(\cdot)$ does not take the form $f(q) \equiv fq$, i.e. if it is not linear (through the origin), then participants and nonparticipants face different tradeoffs between quality and delays.[25] For instance, if $f(\cdot)$ is not very steep (e.g. if it is constant), nonparticipants want some standard but do not care very much about its quality relative to participants. This is an incidence question: where do the incremental rents from higher quality accrue, and does this differ according to the level of quality? The answer

[23] David and Monroe (1994) describe a modeling approach in which direct costs are important.

[24] See, for example, RTG (2004, page 6). Such an increase in switching costs may well (though it does not necessarily) increase prices and profits of the wireless carriers: see Farrell and Klemperer (2004).

[25] This will also be true, of course, if they have different discount rates, but this seems less interesting.

will depend on the details of user tastes and of competition among vendors.

Closely allied to this question is the tradeoff between speed and completeness of a standard. If an incomplete standard (or "model") can be adopted relatively easily and therefore quickly, is it worth the extra delay in order to make the standard more complete, and thus either ensure full interoperability or at least reduce the cost and increase the quality of converters? Again, this is an incidence question: who bears the costs of converters? For instance, if the costs of converters fall primarily on users while the costs of delays are shared between vendors and users, we would suspect that the vendors are inclined to set the rules in such a way as to over-use converters and under-use standardization, relative to the overall efficient solution. The side that has higher *proportional* losses is less ready to accept speedy incomplete standardization.[26]

6 Conclusion

In evaluating rules for formal standardization, both discrimination and speed count. Voluntarism and a concern for consensus lead to the war of attrition, which discriminates well in our simple model but is slow. Moreover, a more realistic model might darken the rosy conclusion of Proposition 2: willingness to wait may be imperfectly correlated with quality, for instance if vested interest is asymmetric.

Where installed base or proprietary technology lead to significant vested interest, it might be more efficient to stress speed even at the expense of screening for quality — perhaps using a combination of voting rules and vendor-neutral participants to help break deadlocks. Where vested interest is important and where the quality of proposals is likely to be similar, it may also be more efficient to have a less careful process or a predetermined standard-setter. The model also suggests that when vested interests are significant, intellectual property rules that limit vested interest not only reduce delays but can even improve technology development incentives.

[26]Some surprising results can arise in such an analysis. For example, in the special duopoly model of Farrell and Saloner (1992), less-efficient converters hurt firms' profits but actually (because of oligopoly price effects) help consumers; thus, if a stricter model makes more efficient converters possible, firms are inclined to try too hard to reach agreement on a strict standard. Cheaper converters, on the other hand, help both firms and consumers; the question therefore becomes whose surplus is more dramatically affected by cheaper converters. That is, which is larger: the elasticity of consumer surplus with respect to converter cost, or the same elasticity for profits? Calculations from equations (15) and (16) of Farrell-Saloner show that the comparison is ambiguous: so, if a stricter model makes cheaper converters possible, it is ambiguous whether firms go too far or not far enough.

References

2004. *Standards Development Organization Advancement Act of 2004*.

ABA. 2003. *Resources Relating to Antitrust and Standards Setting*.

ANSI. 1991. *Procedures for the Development and Coordination of American National Standards*. Tech. rept. American National Standards Institute.

ANSI. 2002 (March). *ANSI Procedures for the Development and Coordination of American National Standards*. Tech. rept. American National Standards Institute.

ANSI. 2003 (March). *Guidelines for Implementation of the ANSI Patent Policy*. Tech. rept. American National Standards Institute.

ANSI. 2006 (January 31, 2006). *ANSI Essential Requirements : Due Process Requirements for American National Standards*. Tech. rept. AMerican National Standards Institute.

Anton, J., & Yao, D. 1995. Standard-setting Consortia, Antitrust, and High-technology Industries. *Antitrust Law Journal*, **64**(1), 247–265.

Arthur, W. Brian. 1989. Competing Technologies, Increasing Returns, and Lock-In by Historical Small Events. *Economic Journal*, **99**, 116–131.

Berg, John L., & Schumny, Harald. 1990. *An Analysis of the Information Technology Standardization Process*. Amsterdam: North-Holland.

Besen, S. M. 1991. European Telecommunications Standards Setting: A Preliminary Analysis of the European Telecommunications Standards Institute. *Telecommunications Policy*.

Besen, S. M., & Farrell, J. 1991. The Role of the ITU in Standardization - Pre-Eminence, Impotence or Rubber Stamp. *Telecommunications Policy*, **15**(4), 311–321.

Besen, S. M., & Farrell, J. 1994. Choosing How to Compete - Strategies and Tactics in Standardization. *Journal of Economic Perspectives*, **8**(2), 117–131.

Besen, S. M., & Johnson, Leland. 1988. *Compatibility Standards, Competition and Innovation in the Broadcasting Industry*. Tech. rept. R-3453-NSF. RAND.

Besen, S. M., & Saloner, G. 1989. The Economics of Telecommunications Standards. *Pages 177–220 of:* Crandall, R., & Flamm, K. (eds), *Changing the Rules: Technological Change, International Competition, and Regulation in Telecommunications*. Washington: Brookings.

Bliss, C., & Nalebuff, B. 1984. Dragon Slaying and Ballroom Dancing: The Private Supply of a Public Good. *Journal of Public Economics*, **25**, 1–12.

Bradner, S. 1996 (October). *RFC 2026: The Internet Standards Process – Revision 3.* Tech. rept. Internet Engineering Task Force.

Bradner, S. 2003a (April). *Intellectual Property Rights in IETF Technology.* Internet Draft (draft-ietf-ipr-technology-rights-05). Internet Engineering Task Force.

Brim, Scott. 2004 (February). *Guidelines for Working Groups on Intellectual Property Issues (RFC 3669).* Tech. rept. Inetrent Engineering Task Force.

Bulow, J., & Klemperer, P. 1999. The Generalized War of Attrition. *American Economic Review*, **89**(1), 175–189.

Busch, L. A., & Wen, Q. 1995. Perfect Equilibria in a Negotiation Model. *Econometrica*, **63**(3), 545–565.

Cargill, Carl F. 1989. *Information Technology Standardization : Theory, Process, and Organizations.* Bedford, MA: Digital Press.

Cargill, Carl F. 1997. *Open Systems Standardization : A Business Approach.* Upper Saddle River, NJ: Prentice Hall PTR.

Cargill, Carl F. 2001. *Evolutionary Pressures in Standardization : Considerations on ANSI's National Standards Strategy.* Tech. rept. Testimony Before the U.S. House of Representatives Science Committee.

Chiao, B., Lerner, J., & Tirole, J. 2005. *The Rules of Standard Setting Organizations: An Empirical Analysis.*

David, P. A. 1985. Clio and the Economics of QWERTY. *American Economic Review*, **75**(2), 332–337.

David, P. A., & Greenstein, S. 1990. The Economics of Compatibility Standards: An Introduction to Recent Research. *Economics of Innovation and New Technology*, **1**, 3–42.

David, P. A., & Monroe, H. K. 1994. Standards Development Strategies Under Incomplete Information–Isn't the "Battle of the Sexes" Really a Revelation Game. *manuscript.*

Davies, E., & al., et. 2004 (May). *IETF Problem Statement.* Request For Comments 3774. Internet Engineering Task Force.

Davies, E., Hoffmna, J., & al., et. 2004. *IETF Problem Resolution Process.*

Ergas, Henry. 1986. Information Technology Standards: The Issues. *Telecommunications*, September, 127–133.

Farrell, J., & Klemperer, P. 2004. Coordination and Lock-in : Competition with Switching Costs and Network Effects. *In:* Armstrong, M., & Porter, R. (eds), *Handbook of Industrial Organization*, vol. 3. North-Holland - forthcoming.

Farrell, J., & Saloner, G. 1988. Coordination through Committees and Markets. *Rand Journal of Economics*, **19**(2), 235–252.

Farrell, J., & Saloner, G. 1992. Converters, Compatibility, and the Control of Interfaces. *Journal of Industrial Economics*, **40**.

Farrell, J., & Shapiro, C. 1992. Standard Setting in High-Definition Television. *Brookings Papers on Economic Activity*, 1–93.

Farrell, J., Pil Choi, J., Edlin, A., Greenstein, S., Hall, B. H., & Saloner, G. 2004 (April 15, 2004). *Brief Amicus Curiae of Economics Professors and Scholars*. Tech. rept. In the Matter of Rambus Incorporated.

Fernandez, R., & Glazer, J. 1991. Striking for a Bargain between 2 Completely Informed Agents. *American Economic Review*, **81**(1), 240–252.

FTC. 2002. *Competition and Intellectual Property Law and Policy in the Knowledge-Based Economy*. Tech. rept. Federal Trade Commission.

FTC. 2003. In the Matter of Rambus Incorporated. *In: FTC*. FTC Docket No. 9302.

Fudenberg, D., & Tirole, J. 1986. A Theory of Exit in Duopoly. *Econometrica*, **54**, 943–960.

Harris, Charon J. 1992. Advanced Television and the Federal Communications Commission. *Federal Communications Law Journal*.

Hawkins, R., Mansell, Robin, & Skea, Jim. 1995. *Standards, Innovation and Competitiveness : The Politics and Economics of Standards in Natural and Technical Environments*. Hants England ; Brookfield, Vt., US: Edward Elgar.

IEC. 1994. *Annual Report*. Tech. rept. International Electrotechnical Commission.

ISO/IEC. 1998. *Directives*. Tech. rept. International Electrotechnical Commission and International Organization for Standards.

ISO/IEC. 2004. *Directives*. Tech. rept.

Jehiel, P., & Moldovanu, B. 1995. Negative Externalities May Cause Delay in Negotiation. *Econometrica*, **63**(6), 1321–1335.

Katz, M. L., & Shapiro, C. 1985. Network Externalities, Competition, and Compatibility. *American Economic Review*, **75**(3), 424–440.

Kolodziej, Stan. 1988. Egos, Infighting, and Politics: Standards Process Bogged Down. *Computerworld*, September 7, 17–22.

Lemley, M. 2002. Intellectual Property Rights and Standard Setting Organizations. *California Law Review*, **90**, 1889–1981.

Lerner, J., & Tirole, J. forthcoming. A Model of Forum Shopping with Special Reference to Standard Setting Organizations. *American Economic Review*.

Lerner, J., Tirole, J., & Stojwas, marcin. 2003. *Cooperative Marketing Agreements Between Competitors: Evidence From Patent Pools*.

Majoras. 2005. Recognizing the Procompetitive Potential of Royalty Discussions in Standard Setting. *Standardization and the Law : Developing the Golden Mean for Global Trade*.

Mennell, P. 1987. Tailoring Legal Protection for Computer Software. *Stanford Law Review*, **39**, 1329–1372.

Myatt, David. 2005. *Instant Exit from the Asymmetric War of Attrition*.

National, Research Council. 1990. *Crossroads of Information Technology Standards*. Washington: National Academy Press.

RTG. 2004. Reply Comments of the Rural Telecommunications Group. *www.ruraltelecomgroup.org/downloads/CompetitionReportComments.pdf*.

Rysman, M., & Simcoe, T. 2006. *Patents and the Performance of Voluntary Standard Setting Organizations*.

Saloner, G. 1990. Economic Issues in Computer Interface Standardization. *Economics of Innovation and New Technology*, **1**, 135–156.

Shaked, A. 1987. *Opting out : bazaars versus "high tech" markets*.

Shapiro, C. 2000. *Setting Compatibility Standards: Cooperation or Collusion?*

Shapiro, C. 2001. Navigating the Patent Thicket: Cross Licenses, Patent Pools and Standard-Setting. *In:* Jaffe, A., Lerner, J., & Stern, Scott (eds), *Innovation Policy and the Economy*, vol. 1. Cambridge: MIT Press.

Shapiro, Carl, & Varian, Hal R. 1998. *Information Rules : A Strategic Guide to the Network Economy*. Boston, Mass.: Harvard Business School Press.

Siegel, Jon. 2002. Return-on-Investment (ROI) from Consortium Membership for End-User Companies. *Pages 225–231 of:* Bolin, Sherrie (ed), *The Standards Edge*. Ann Arbor, MI: Sheridan Books.

Simcoe, T. 2005. *Standard Setting Committees*.

Simcoe, T. 2006. Explaining the Increase in Intellectual Property Disclosure. *In:* Bolin, S. (ed), *The Standards Edge*, vol. 3. forthcoming.

Sirbu, M., & Zwimpfer, L. 1985. Standard Setting for Computer Communication: The Case of X.25. *IEEE Communications Magazine*, **23**(3).

Swann, G.M.P. 1990. Standards and the Growth of a Computer Network. *In:* Berg, John L., & Schumny, Harald (eds), *An Analysis of the Information Technology Standardization Process*. Amsterdam: North-Holland.

Teece, D. J., & Sherry, E. F. 2003. Standards setting and antitrust. *Minnesota Law Review*, **87**(6), 1913–1994.

Turner, M., & Weninger, Q. 2005. Meetings with costly participation: An empirical analysis. *Review of Economic Studies*, **72**(1), 247–268.

Wagner, Mitch. 1990. IEEE Hopes to Revive GUI Drive. *UNIX Today*, June 25, 48.

Weiss, M., & Sirbu, M. 1990. Technological Choice in Voluntary Standards Committees: An Empirical Analysis. *Economics of Innovation and New Technology*, **1**, 111–134.

Weiss, M., & Toyokuku, R. 1996. Free-ridership in the Standards-setting Process: the case of 10BaseT. *StandardView*, **4**(4), 205–212.

Appendix : Proofs

Proposition 1 *Every rationalizable Bayesian strategy is weakly increasing: lower quality types concede before higher quality types.*

Proof: Consider two possible types of player 1, $q_L < q_H$. Suppose that q_L puts positive probability weight on conceding at time t_L, and q_H puts positive weight on conceding at time t_H. We will show that $t_L \leq t_H$.

Let Γ be player 1's (perceived) distribution function of t_2, the time when player 2 concedes (if player 1 does not previously do so). Let $\mathrm{E}[q|t] \equiv \mathrm{E}[q_2|t_2 = t]$ be player 1's expected value of player 2's quality q_2 given that player 2 concedes at t. Then, because type q_L is willing to concede at t_L, we have:

$$Wq_L \int_0^{t_L} e^{-rt}\,\mathrm{d}\Gamma(t) + Le^{-rt_L} \int_{t_L}^{\infty} \mathrm{E}[q|t]\,\mathrm{d}\Gamma(t) \geq Wq_L \int_0^{t_H} e^{-rt}\,\mathrm{d}\Gamma(t) + Le^{-rt_H} \int_{t_H}^{\infty} \mathrm{E}[q|t]\,\mathrm{d}\Gamma(t).$$

Similarly, because type t_H is willing to concede at time t_H,

$$Wq_H \int_0^{t_L} e^{-rt}\,\mathrm{d}\Gamma(t) + Le^{-rt_L} \int_{t_L}^{\infty} \mathrm{E}[q|t]\,\mathrm{d}\Gamma(t) \leq Wq_H \int_0^{t_H} e^{-rt}\,\mathrm{d}\Gamma(t) + Le^{-rt_H} \int_{t_H}^{\infty} \mathrm{E}[q|t]\,\mathrm{d}\Gamma(t).$$

Subtracting the first of these inequalities from the second we get

$$W(q_H - q_L) \int_0^{t_L} e^{-rt}\,\mathrm{d}\Gamma(t) \leq W(q_H - q_L) \int_0^{t_H} e^{-rt}\,\mathrm{d}\Gamma(t) \tag{11}$$

If $t_L > t_H$, (11) would imply that there is zero probability of player 2 conceding between t_H and t_L. But then no type of player 1 should concede at $t_L > t_H$ (it would be better to concede sooner, at or just after t_H), contradicting our assumption that q_L can optimally concede at t_L. Thus indeed $t_L \leq t_H$. Q.E.D.

Proposition 2 *In the symmetric equilibrium of the war of attrition, each player's strategy implies a continuous and gap-free distribution of concession time. Consequently, the winner is the higher-quality system.*

Proof: Suppose that each player's strategy $t_i(\cdot)$ had an atom at t: that is, there is positive probability of concession exactly at t. Let $\bar{q}(t)$ be the supremum of the set of types who can optimally concede at t. By continuity of the payoff function, type $\bar{q}(t)$ also can optimally concede at t.

But by waiting until just after t, type $\bar{q}(t)$ would increase its probability of winning and could not reduce the quality of the system that emerges. Hence its payoff would increase. This contradicts the statement that it can optimally concede at t. Thus the distribution of concession time cannot have atoms.

To see that the distribution of concession time cannot have gaps, suppose that no concessions take place in the gap (t_L, t_H). Then the lowest type that (in the hypothetical equilibrium) can optimally concede at t_H would do better to concede just after t_L: it would not reduce its probability of winning nor could it lower the quality of the system adopted, but it would get its payoff sooner. Therefore there are no gaps in the distribution of concession time.

Consequently, if q is continuously distributed, the symmetric equilibrium strategy is one-to-one; thus the war of attrition selects the higher-quality system because concession time t is strictly increasing in quality q.

If the distribution of q has (say) an atom at $\hat{q}$, then that type will randomize its concession time (creating a concession-time distribution without atoms). By Proposition 1, this randomization will be on an interval $[t_L, t_H]$, and types below $\hat{q}$ will concede at or before t_L and types above $\hat{q}$ will concede at or after t_H. Consequently, atoms in the q distribution will not lead with positive probability to the choice of an inferior system. This establishes the Proposition. Q.E.D.

Appendix : Other Policies to Reduce Delay

Standards organizations are very concerned about delays, and try to reduce them.[27] Our model suggests that delays will shrink if v is reduced, and that given the war-of-attrition structure, the distribution of q, and v, other strategies intended to reduce delays may be ineffective. In this Appendix we apply this idea to a number of policies meant to reduce delays.

6.1 Intellectual Property Rules

Most SSOs have intellectual property rules concerning members' duties to search for, disclose, and license any proprietary technology that is part of a standard. Perhaps the most common such policy is the "reasonable and non-discriminatory" or RAND licensing requirement.[28] Loosely, RAND policy requires a promise to license any essential technology liberally. For example, ANSI rules require that any patented technology used in a proposed standard be licensed either "without compensation" or "under reasonable terms and conditions that are demonstrably free of any unfair discrimination."[29] Similarly, the ISO's *Directives* require a promise from patent-holders to "negotiate worldwide licences... with applicants throughout the world on reasonable and non-discriminatory terms and conditions."[30]

While a RAND licensing requirement clearly precludes exclusive deals, the SSO usually leaves interpretation of "reasonable and non-discriminatory" to patent holders and prospective licensees (and courts). For example, ANSI's patent policy *Guidelines* state that "the determination of specific license terms and conditions, and the evaluation of whether such terms are reasonable and demonstrably free of unfair discrimination, are not matters that are properly the subject of discussion or debate at a development meeting" (ANSI 2003, page 6).

Given SSOs' reluctance to get involved in licensing disputes (which many observers link to antitrust concerns) and the secrecy surrounding many licenses, we know relatively little about the actual licensing of essential IPR. And while most SSOs reserve the right to revoke a standard if

[27] Besen and Farrell (1991) describe competitive pressures that may be part of the motive for these efforts, and Cargill (2001) suggests that formal SDO membership has declined because consortia and other informal fora work faster.

[28] Lemley (2002) and Chiao, Lerner and Tirole (2006) survey IPR policies; Teece and Sherry (2003) and Farrell, Hayes, Shapiro, and Sullivan (2007) discuss SSOs' IPR policies and antitrust.

[29] Appendix I, "ANSI's Patent Policy", in ANSI (2006). ANSI does not mention copyright protection, presumably since historically copyright did not protect things that might be needed for compliance to a standard. Recently, however, this has begun to change, since much software is protected by copyright, and since compatibility at the user interface often requires that a "look and feel" be imitated. See for instance Menell (1987) and Samuelson (2006).

[30] International Organization for Standardization, *Directives*, 2001, Part 1, Section 2.14.2.

there is evidence that essential IPRs cannot be obtained under RAND terms, it is not clear whether this sanction is likely to be pursued, particularly when implementation requires substantial (sunk) investments.

Disclosure rules are another dimension of intellectual property policy. Many SSOs, including most with a RAND licensing rule, require members to disclose IPRs that could be relevant to a proposed standard, and encourage them to do so as soon as possible. The ANSI *Guidelines* state that "early disclosure of patents is likely to enhance the efficiency of the process used to approve and finalize standards." (ANSI 2003, page 5).

In practice, disclosure rules do not appear to be very strictly enforced. There may be no obligation to search for relevant IPR, and it is often unclear when and whether firms should disclose pending patent applications. Simcoe (2006) and Rysman and Simcoe (2006) found that many disclosures promise to grant RAND licenses but do not identify specific patents or pending applications.[31] Disclosures can also occur late in the standard-setting process—potentially well past the emergence of a consensus. This is no doubt partly because it becomes easier to identify relevant IPR as the technical parameters of the final standard emerge.[32] However, firms may also delay IPR disclosures to encourage the adoption of standards that read on their own patents.

The combination of imperfectly enforced licensing standards, loosely enforced disclosure requirements, and platform-specific investments has led to a number of high-profile disputes over intellectual property in consensus standards. In Section 4 we evaluate the impact of strengthening intellectual property policies (in a way that reduces v) on the participants' incentive to innovate.

6.2 Voting Rules

Given the extent of vested interest, one can try to reduce its power to delay agreement. One change in this direction is to weaken the consensus principle. While the consensus principle does not exactly confer veto power on each interested party (as in the model), it at least enables important participants to hold up an agreement.[33] Davies (2004) writes, referring to the IETF:

"A single vocal individual or small group can be a particular challenge to Working Group

[31] This matters to the extent that an SSO or its members might respond to disclosure in ways other than merely demanding a RAND assurance. See Teece and Sherry (2003) and Farrell et al. (2007).

[32] To the extent that RAND policies do commit SSO participants to liberal licensing terms for their IPR, some vendors may actually try to incorporate their rivals' IPR in a standard. This could happen if, for example, one vendor holds strong IPR rights over a particular functionality that could be left optional.

[33] For example, IEEE procedures require a thorough review and response to every negative comment received on a given ballot. A recent vote in the 802.11n wireless networking committee produced more than 3,000 such comments. "Wave of Commentary delays new WLAN standard." Robert W. Smith, Heise Online, May 2006.

> progress and the authority of the chair. The IETF does not have a strategy for dealing effectively with an individual who is inhibiting progress, whilst ensuring that an individual who has a genuine reason for revisiting a decision is allowed to get his or her point across."

In response, some standards bodies specify that a defined super-majority can approve a draft standard. Besen (1989) describes how the European Telecommunications Standards Institute (ETSI), formed in 1988, replaced the consensus principle by a system of weighted voting (when consensus "cannot be achieved")[34] that allows adoption of a standard on a 71-percent weighted majority. The ISO allows for draft international standards approved by a two-thirds majority (of "P-members") provided that "every attempt shall be made to resolve negative votes."[35] The ITU has a similar voting provision (see Besen and Farrell 1991). OASIS, a consortium that develops software standards for exchanging business information, has a voting rule that allows two-thirds of the membership to approve a proposal provided that no more than twenty-five percent object.[36]

Our two-player model cannot analyze the effects of changes in voting rules. However, the results in Section 3 suggest that SSOs that successfully recruit "vendor neutral" participants may be able to realize better outcomes when they require "less" consensus, so that these players become pivotal in the voting process.

6.3 Standardizing Early to Reduce Vested Interest

Vested interests are growing all the time as installed bases grow or proprietary knowledge develops. As when one sets off on a commute just before rush-hour, every delay in starting means a bigger delay in finishing. Thus, some observers urge "anticipatory standardization" in advance of the market, before vested interests grow strong. For example, one participant states that[37]

> "...to do any good, committees must be organized before the camps have formed around competing standards. It's much easier to establish a standard before the market has [formed] than to go back and get a number of competing vendors to agree upon one... Once vendors have brought competing products to market,... there's often no hope of a clear standard emerging. One such futile effort is the attempt by manufacturers of competing RISC chips to reach a standard."

[34] Whether one calls super-majority voting an alternative to consensus, as that phrasing suggests, or a form of consensus, is just a verbal matter.

[35] IEC/ISO *Directives*, part 1, section 2.4.3.

[36] See the OASIS bylaws at www.oasis-open.org/who/bylaws.php

[37] "Users fear Standards Groups Act as Vehicles for Vendors' Interests," *Infoworld*, 12/5/88, page 1,8. See also a quote from the chair of the T1 committee, in Dorros (1990), and Dorros' agreement (page 38).

Standardizing in advance seems likely to reduce vested interest, and hence reduce delay, but to reduce both the opportunities for product development and the reliability of screening for quality.[38] It could thus be viewed as a move towards random choice.

Some practitioners suggest that parallel anticipatory standard setting efforts can limit the cost of technological short-sightedness and preserve the benefits of starting before vested interest sets in. For example, Updegrove describes benefits associated with the development of multiple wireless standards:[39]

> "The difficulty of predicting the future when setting anticipatory standards is clearly demonstrated by the example of early wireless data standards development. HomeRF disappeared, Bluetooth found a home in one set of short-range applications, and Wi-Fi predominated for longer distances... over time, it became clear which standard was optimally useful within areas of overlap. If all of these standards hadn't been launched in anticipatory mode, then large gaps may have been left in the standards landscape"

When multiple efforts do not overlap, the parallel approach may preserve technological flexibility — though it is likely to create a future demand for converters. However, when anticipatory standards do overlap and rival firms commit themselves to a particular specification, parallel development efforts can *increase* vested interests in the final push for a common standard. For example, the IEEE's 802.15.3a committee disbanded after three years of work when rival factions, each with its own consortium, could not reach a compromise on protocols for ultrawideband wireless networking.[40]

6.4 Incomplete Standardization to Sidestep Conflict

In practice, formal standards do not always ensure compatibility: not every two "conforming" products are interoperable. One reason is that, partly in response to the uncertainty about feasibility, cost, and demand that results from standardizing early, but also as another strategy to reduce the delays due to vested interest, a standard will often include incompatible or "vendor-specific" options. For instance, Sirbu and Zwimpfer (1985) describe how incompatible options were included in the X.25 packet switching standard in order to placate intractable vested interest (more than one system already had an installed base). Similarly, Kolodziej (1988) relates that an impasse in negotiating a PC modem standard (V.42) in the CCITT was overcome by deciding "to put both protocols into the standard."

[38] One well-known example of an anticipatory standard that failed to anticipate future demand is the physical-address space in IPv4 — i.e. a computer's 16-bit Internet address.

[39] "Is One Standard Always Better than Two?," Andrew Updegrove, Consortium Standards Bulletin, 18 December 2005 (www.consortiuminfo.org/standardsblog/article.php?story=20060126105734863).

[40] "UWB Standards Group Calls it Quits," Mark Hachman, Computerworld, January 19, 2006.

Such a "model" — an incompletely-specified standard, or a menu of choices — is meant to ensure a baseline level of interoperability. But when firms make different choices from the menu, their products may not be fully compatible.[41] This creates a demand for "strict" standards, sometimes called profiles. These profiles are typically developed outside formal SDOs: by user groups, by governments, or by less formal consortia and standards fora. Sometimes, as in ISO, the original organization then "certifies" profiles — an ironic twist.[42]

Although a model does not ensure compatibility, it greatly helps in achieving it. The market, or other organizations, can more easily choose a profile within a model than choose a standard from scratch: not all possible (or even proposed) options need be included, and many uncontroversial issues may be standardized. It is often easier, cheaper, and more effective to patch together compatibility through converters within a model than it would be if competing technologies did not respect a model. For example, while every Internet device shares a common networking protocol (TCP/IP), the Internet's various physical networks use different transport protocols and communicate with each other through a series of converters (gateway protocols) developed and maintained by the IETF.

6.5 Meeting More Often

Committees charged with developing a consensus standard typically meet only periodically. A natural initiative toward reducing delays is meeting more often. Presumably, this provides more time to work out technical issues; and, once consensus emerges, more frequent plenary or official meetings to finish the process can help.[43]

But to the extent that, as in the model, the work is largely bargaining, the time to agreement is determined by screening constraints, and meeting more often is unlikely to reduce delays (unless it noticeably increases flow costs of delay to the participants). Indeed, the model above assumes perpetual meetings, but the delays persist.

As this reasoning suggests, SDOs may have had more success in accelerating post-consensus administrative processing than in speeding consensus. In its 1994 *Annual Report* (page 4), the IEC

[41] For example, the DHCP protocol that computers use to acquire an Internet address is designed to work with any operating system. However, the protocol includes vendor-specific options, and users often have greater functionality when, say, a Windows computer connects to a network running Microsoft's DHCP server.

[42] ISO has recognized a number of profile developers and formed "Feeders' Forums" to coordinate their activities and to propose profiles for special recognition by ISO itself. See for instance "The standards deluge: a sound foundation or a tower of Babel?" *Data Communications*, September 1988, especially pages 163–164.

[43] For example, until 1989 the ITU would formally approve standards only at plenary meetings held once every four years. As a result of reforms intended to reduce delays, it is now said to be on a "perpetual standards-creation basis", so that standards can be approved at any time. See, for example, B. Crockett, "ITU takes steps to speed up standards process," *Network World*, 9 October 1989, page 30; see also Besen and Farrell (1991).

noted that, "Time for the fundamental part of standards production — preparatory and technical development stages... has remained substantially the same, while time for the latter stages of approval and publication... has been brought down by 60 percent." Some less formal SSOs, such as the IETF and W3C, use the Internet to speed review and approval, but Simcoe (2005) finds that even at the IETF — where the average proposal duration is roughly two years — strong vested interest often leads to substantially longer delays.[44]

[44] For anecdotal evidence on vested interest and delay at the IETF, see Higgins (1997) or Brim (2004).