Choosing the Rules for Formal Standardization

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Abstract. Formal standardization – explicit agreement on compatibility standards – has important advantages over *de facto* standardization, but is marred by severe delays. I explore the tradeoffs between speed and the quality of the outcome in a private-information model of the war of attrition and alternative mechanisms, and show that the war of attrition can be excessively slow. I discuss strategies to reduce delay, including changes in intellectual property policy and in voting rules, early beginnings to standardization efforts, and the use of options.

♣ Even supposedly backward-compatible software isn't always, and while the body of the paper below is (newly) pdf'd from the 1996 file, this title page and the references have had to be re-processed (March 2002); I am doing this in part because I hope soon to rescue this paper from my own "severe delays."

Compatibility standards often are developed through a process of explicit consensus. When participants have little vested interest in particular outcomes, the process will be straightforward — participants working together to find the best technical solution. If anything, there might be a free-rider problem, as development of the standard could be a public good. But participants often do have strong vested interests, and while this helps overcome the free-rider problem, it can make it hard to reach consensus, 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* standards race, but that (on average) it is slow: the equilibrium delays may dissipate a large fraction of the potential gain from the process. This is essentially a bargaining problem and a bargaining inefficiency.

As the modern literature on bargaining suggests, it is useful to make explicit the private information that drives bargaining behavior and bargaining inefficiencies. In this paper, accordingly, I develop an incomplete-information war-of-attrition model to assess the performance of consensus standardization. I find that the predicted delays are often long enough to make the process perform very poorly, even on a somewhat optimistic view of its merits. Standards organizations' policies that reduce vested interest may help in

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reducing delays; in particular, intellectual-property policies akin to compulsory licensing are likely to speed the process and do not necessarily reduce the incentives to innovate. On the other hand, some policies intended to reduce delays, but not acting on vested interest, may be stymied by the fundamental bargaining incentives.

1. The Formal Standards Process: Description and Delays

Standards-developing organizations (SDOs) try to replace the bandwagon *de facto* standards process with an orderly explicit search for consensus. This process mingles technical discussion and political negotiation, in contrast to the race for market share and the battle for users' expectations that typify the *de facto* standards process.[1]

The active participants are "volunteers" willing to spend substantial time and travel money.[2] Some commentators, such as Weiss and Toyofuku (1993), have stressed the resulting incentives for free-riding. In particular, users, whose interests are typically more diffuse than vendors', are often thought to be badly underrepresented.[3]

However, when firms have vested interests in particular solutions, participation may be less of a problem but agreement may be hard to reach. Kolodziej (1988) writes, "Politics can become especially entangled when vendors already have a vested interest in the technology being brought to the standards table," and quotes a member of an IEEE standards committee as saying that "when there is 'silicon', or component products, already available in the market, it will always cause problems in standards work."[4] Even absent physical installed base, vendors may have proprietary complementary technologies; if there

[1] For a fuller description see for instance Cargill (1989).

[2] The direct pecuniary costs of formal standards activities for information-technology firms have been estimated at around 1% of revenues — Swann (1990, page 472) quotes estimates of 0.5%, 1%, and 2.5%. Participation in a single committee may cost $250,000 annually, according to an estimate by Professor Michael Spring, quoted in *Datamation*, September 1, 1989, page 64.

[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] Gabel (1987, section 5) suggests that X/OPEN selected UNIX as a standard operating system for mainframe computers precisely because it was equally unfamiliar to all the members of X/OPEN.

is firm-specific learning by doing, each firm will have a cost advantage in producing to its "own" standard even if the standard itself is made public; and generally firms with different strategic foci may prefer different standards.

In principle, one might imagine a broad range of decision mechanisms for a standards organization, designed to take into account parties' information, their participation constraints, and the need to produce standards that will attract widespread support (most consensus standards are voluntary). It seems, however, that standards organizations recoil from any element of compulsion — *ex ante* or *ex post*. There are of course reasons for this, notably antitrust concerns,[5] but here I focus on its implication: although standards can be adopted over some opposition, the institutions almost desperately seek "consensus," defined by the American National Standards Institute (ANSI) as the finding that:

> "substantial agreement has been reached by directly and materially affected interest categories. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution."[6]

ANSI (1987) requires more specifically that a standard obtain at least a two-thirds majority of those voting and a majority of the membership (section A8.3), and that unresolved negative views and objections be formally addressed (section A9.1, part 11). Similarly, the International Organization for Standardization (ISO) specifies that "the decision to register a committee draft as a draft International Standard shall be taken on the basis of the consensus principle." It defines consensus as[7]

> "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."

[5] Even some who doubt that there is a serious threat of anticompetitive behavior agree that there is a serious threat of such allegations, and that the fear of (even baseless) suits constrains the process. See Anton and Yao (1995) for a general discussion of antitrust and standardization, and Federal Trade Commission (1983) for some antitrust concerns related to standard-setting, although mostly related to quality rather than compatibility standards. Cargill (1989, p. 106), discussing the widespread Accredited Organization method of standards development, notes that "the potential use of standards to protect the status quo is a constant worry .... There is a great temptation to standardize only upon things that are familiar to the majority of the members." See ANSI (1987) or Rockwell (1990) on the need for careful and time-consuming procedures when there is actual or potential conflict over a standard.

[6] ANSI (1987) section 1.3.3.

[7] IEC/ISO *Directives*, 1989, part 1, section 2.4.3. IEC is the International Electrotechnical Commission.

As a result, although consensus need not imply unanimity, the parties most directly concerned can often block or at least delay the adoption of a standard they dislike. In the case I consider, where two or more parties want there to be a standard but differ on their preferred standards, this turns the coordination game into a war of attrition.

Delays in Formal Standardization

Viewing formal standardization as a war of attrition suggests that we should expect delays in reaching consensus. Indeed, formal consensus standardization is often very slow, despite efforts to hasten the process. Cargill (1989, page 114) reports that reaching a standard takes "an average of four years to complete; much more, if [it is] controversial". Kolodziej (1988) estimates four to five years as an average. In 1981 the chairman of the IEEE Standards Board cited seven years as an average delay for an IEEE standard (Lee, 1981). At the International Organization for Standardization (ISO), the average elapsed time in developing standards during 1987–1991 ranged from six years (1991) to well over seven (1988). In its 1991 *Annual Report* the International Electrotechnical Commission (IEC) set a goal of reducing the standards development cycle to "a maximum of five years, and a mean time of very much less,"(page 2), from a previous figure of 87 months (page 6); but its 1994 *Annual Report* (page 4) reported a mean development time of just over five years.

Participants and observers complain fiercely about these delays. For example, in a National Research Council survey of responses to the question "What issues in the US standards developing process must be resolved?", the first point listed was that "the adoption process is too slow."[8]

2. Outline of the Paper

In section 3, I develop 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." I show that in the

[8] National Research Council (1990), page 21.

symmetric equilibrium the better proposal wins. In section 4, I assess the performance of this symmetric equilibrium, taking account of its selection of the better proposal and of its delays. In a simple example, I 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. In section 5, I use this analysis to discuss attempts to reduce delays. The model predicts that policies that reduce vested interest, or make it less powerful, will likely reduce delays, but that those that do not will be relatively unsuccessful. In section 6, I address the concern that reducing "vested interest," particularly through the kind of intellectual-property policy that many standards organizations adopt, might reduce incentives to develop the proposals on which the model is based. I show that the countervailing effect of faster adoption may outweigh the obvious adverse effect, so weaker intellectual property protection may actually increase incentives to innovate. In section 7, I address the concern that some interested parties — notably users — are underrepresented because their interests are too diffuse to induce them to participate. I ask how their *ex ante* preferences are likely to differ from active participants' (mostly vendors'). Section 8 concludes.

3. A Model

Two proponents have developed systems, which may differ in "quality" (which is private information), and must agree on one as a standard. Each player would like a high-quality standard adopted, but also would like its own system adopted as the standard. Specifically, each player $i = 1, 2$ has a privately known quality q_i, and can concede at any time, ending the game. That is, each chooses a concession time t_i; if $t_1 \leq t_2$ then player 1 concedes at time t_1, and as of that date it 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 total surplus q; we normalize when convenient so that $L + W = 1$. The players share a discount rate r, and flow payoffs are zero until agreement is reached (that is, I assume that the market waits until there is a standard).

If we had $L = W$ then both players would want the player with lower quality to concede, and a sensible model would predict rapid and efficient agreement in this case.

When $W > L$ there is "vested interest," and we assume this henceforth. Thus each player would rather its rival concede, even if its rival has a somewhat higher quality. This creates a private-information war of attrition, in which each player's strategy is the time at which it will concede if the other has not already done so. We consider a symmetric model, and focus on the symmetric perfect Bayesian equilibrium. Thus we look for 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 rivals is also using the strategy $t(\cdot)$.[9]

I assume that there are no side payments: this is my understanding from a number of conversations with standards officials and participants. Side payments would likely also raise antitrust concerns. For simplicity, I also assume that agreement must take the form of one party conceding or agreeing to the other's proposal: in general there is no obvious channel for compromise, although it may sometimes be possible.

A Screening Property

In Propositions 1 and 2 I show that in the symmetric perfect Bayesian equilibrium of the war of attrition, the better system wins.

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

Proof. Consider any two possible types of a player (say player 1), q_L and q_H, with $q_L < q_H$. 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:

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

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

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

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

Subtracting the first of these inequalities from the second we get

$$W(q_H - q_L) \int_0^{t_L} e^{-rt}\,\mathrm{d}\Gamma(t) \leq W(q_H - q_L) \int_0^{t_H} e^{-rt}\,\mathrm{d}\Gamma(t). \tag{1}$$

If $t_L > t_H$, (1) 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 t_H), contradicting our assumption that q_L can optimally concede at t_L. Thus indeed $t_L \leq t_H$. ∎

Proposition 1 has an important performance implication. In the symmetric equilibrium of the war of attrition, the "winner" is the player with the later concession time, and by Proposition 1 this is the player with the higher quality proposal. Thus, in this model, the better system will eventually be chosen. We formalize this as a proposition and provide a formal argument:

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 interval (t_L, t_H). Then the lowest type that (in the hypothetical equilibrium) can optimally concede at t_H would do better to concede at 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. ∎

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

First, in general the war of attrition selects for willingness to wait. In my simple model, differences in willingness to wait are caused solely by differences in quality, so that selection is ideal. This clearly overstates the case. In particular, as Katz and Shapiro (1985) emphasized, small firms often are keener to have a standard than are large firms, so the war of attrition may favor large firms' proposals as well as high-quality proposals.

Second, Proposition 2 concerns the symmetric equilibrium. There is also an asymmetric equilibrium in which player 1 never concedes and player 2 concedes immediately,[10] as well as the mirror-image equilibrium. In *ex ante* symmetric situations, the symmetric equilibrium seems a natural model. However, if one player is (generally perceived as) the standard-setter, an asymmetric equilibrium may be the right description. Historically, IBM may have played this role in the computer industry, and AT&T in US telecommunications.

[10] 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.

Properties of Equilibrium for Continuous Distributions

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

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

Observe that

$$G'(q) \equiv h(q)[G(q) - q], \tag{2}$$

where of course h denotes the hazard rate,

$$h(q) \equiv \frac{F'(q)}{1 - F(q)}.$$

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

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

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)

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

Using (2) this becomes

$$0 = [W - L]hqq' - rLG. \tag{3}$$

We can separate (3) as

$$r\,\mathrm{d}t = v\frac{qh(q)}{G(q)}\,\mathrm{d}q, \tag{4}$$

where $v \equiv (W - L)/L \geq 0$.[11] This differential equation, together with the boundary condition that $q = q_{min}$ at $t = 0$, defines the symmetric Bayesian equilibrium of the private-information war of attrition.

[11] Thus, with our normalization $L + W = 1$, we have $W = (v + 1)/(v + 2)$ and $L = 1/(v + 2)$.

To solve this, define

$$K(q) \equiv [1 - F(q)]G(q) \equiv \int_q^\infty y \, \mathrm{d}F(y)$$

and note that $K(q_{min}) = \mu$, where μ is the mean of q. Then the solution to (4) with our boundary condition is

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

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

$$\delta(q) \equiv e^{-rt(q)} = \left[\frac{K(q)}{\mu}\right]^v. \tag{5}$$

From (5) we see that r has disappeared — it affects the time to agreement but not the payoffs given both players' types. Indeed, we see that:

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

4. Performance

In this section I analyze the *ex ante* performance (from the players' point of view) of the war of attrition. As a benchmark, I use the alternative robust mechanism of an immediate "random choice." The comparisons of the war of attrition and of "random choice" can be read in two ways. First, they may suggest whether or not it would be wise to move towards a faster process, even at the expense of some loss in the quality of outcome. Second, they let us compare the efficiency of setting standards through a symmetric consensus process against that of having an established standard-setter. These interpretations will differ when we consider incentives to improve q below, but for now they are equivalent: in each case, we get an immediate standard with expected quality μ.

Write $u(q)$ for the (interim) 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; thus we have

$$u'(q) = W \int_{q_{min}}^q \delta(y) \, \mathrm{d}F(y) = W \int_{q_{min}}^q \left[\frac{K(y)}{\mu}\right]^v \mathrm{d}F(y). \tag{6}$$

We can combine (6) with the bottom boundary condition $u(q_{min}) = L\mu$ to get

$$u(q) = L\mu + W \int_{q_{min}}^{q} \int_{q_{min}}^{z} \left[\frac{K(y)}{\mu}\right]^{v} \mathrm{d}F(y)\,\mathrm{d}z. \tag{7}$$

An alternative formulation can be written down simply by accounting for the outcome as a function of the rival's type, say t:

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

or

$$\mu^{v} u(q) = Wq \int_{q_{min}}^{q} K(t)^{v}\,\mathrm{d}F(t) + LK(q)^{v+1}. \tag{8}$$

Unfortunately, I have been unable to use (7) or (8) to derive general properties of performance beyond Proposition 3. So we turn to an example.

An Example

The most tractable example I have found is based on the distribution function $F(x) \equiv 1 - x^{-(1+a)}$ for $x \geq 1$ (where $a > 2$). This distribution has a mean of $(a+1)/(a-2)$; I think of a more as an indicator of dispersion than of mean, however, because the entire model is transparent to multiplication by a constant factor.[12] We have then[13]

$$K(q) = \frac{a+1}{a-2} q^{-(a-2)}.$$

Hence

$$\delta(q) = q^{(2-a)v} \quad (q \geq 1),$$

and

$$u'(q) = \frac{v+1}{v+2} \frac{a+1}{1+(a-2)(v+1)} \left[1 - q^{-[1+(a-2)(v+1)]}\right]. \tag{9}$$

[12] That is, we can consider the generalized model $F(x) \equiv 1 - (x/k)^{-(1+a)}$ for $x \geq k$; here, the mean is $k(a+1)/(a-2)$ but the proportional dispersion is the same as for $k = 1$, *i.e.*, is determined solely by a.

[13] The calculations reported here and below are straightforward but tedious; I did or confirmed them using Mathematica.

Integrating and using the boundary condition at $q_{min} = 1$, which is

$$u(1) = L\mu = \frac{1}{v+2}\frac{a+1}{a-2},$$

we get

$$u(q) = \frac{(1+a)\; q\; \left[q^{1+2\,v-a-av} + (a-2)(v+1)\right]}{(a-2)\;(v+2)\;(1+(a-2)(v+1))}. \tag{10}$$

The lowest type ($q = 1$)'s expected payoff is $L\mu$, and that of a very high type, q, is (asymptotically) equal to Wq times the expected value of $\delta(q)$, which is $(1+a)/[1+(a-2)(v+1)]$.

Taking the expectation of (10) yields the *ex ante* expected payoff (per player), which we use as a measure of performance for the participants:

$$\mathrm{E}u(q) = \frac{(1+a)^2}{(a-2)\;[1+(a-2)(v+2)]}. \tag{11}$$

Comparisons

In the first-best, the expected per-player payoff is

$$\int_{q_{min}}^{\infty} qF(q)\,\mathrm{d}F(q) = \frac{(a+1)^2}{(a-2)(2a-1)}.$$

Under random choice it is $\mathrm{E}u = \frac{1}{2}\mu = (a+1)/[2(a-2)]$.

Thus the war of attrition achieves a fraction

$$\frac{2a-1}{1+(a-2)(v+2)}$$

of the first-best payoff. Perhaps more interestingly, it achieves a fraction

$$\frac{2(a+1)}{1+(a-2)(v+2)}$$

of the payoff achieved under random choice. This latter fraction is greater than 1 if and only if $(a-2)v < 5$.

Proposition 4. *The ex ante payoffs to participants from the war of attrition exceed those from random choice if and only if $v < 5/(a-2)$.*

Because selection for quality is valuable *ex ante*, some vested interest is tolerable, but too much will more than dissipate the gains from selection. A rapid but rough choice (random choice), or a pre-determined standard-setter, is superior for participants if v is large or if a is large. Large v leads to long delays (Proposition 3); a more concentrated distribution of quality (large a) reduces the value of the selection effect. Interestingly, one might expect the most resistance to a predetermined standard-setter precisely when v is large.

Other Examples

Although the example above is the only one I have found tractable in general, it is possible to solve others for the simple case $v = 1$. I report the relative performance of the war of attrition and of random choice, and for a benchmark also that of the first best.

Uniform Distribution. Let q be uniformly distributed on $[m - \frac{1}{2}, m + \frac{1}{2}]$. Then (lengthy but straightforward) calculations along the lines above show that the expected per-player payoff in the war of attrition is

$$\frac{1}{12} + \frac{1}{120\,m} + \frac{m}{3}.$$

In this example the first best yields

$$\frac{1}{12} + \frac{m}{2},$$

while random choice of course yields each player $m/2$. Thus the war of attrition outperforms random choice if and only if $1 + 10m - 20m^2 > 0$, or approximately $m < .59$. Recalling that the range of q is $[m - \frac{1}{2}, m + \frac{1}{2}]$, I interpret this to mean that if the uniform distribution is appropriate, the war of attrition will seldom outperform random choice.

Exponential Distribution Let q be exponentially distributed, with density e^{b-q} for $q \geq b$. Then calculation shows that the war of attrition gives per-player payoffs of

$$\frac{17 + 24b + 9b^2}{27(1+b)}.$$

The first-best payoff per player is

$$\frac{3}{4} + \frac{b}{2},$$

and the random-choice payoff per player is $\frac{1}{2}(1+b)$. Thus, the war of attrition achieves a fraction

$$\frac{4(17+24b+9b^2)}{27(1+b)(3+2b)}$$

of the gains from the first-best; this is decreasing in b (which one can interpret as an inverse measure of relative dispersion of q), and ranges from about .84 when b is very small to 2/3 when b is very large. The ratio of the payoff in the war of attrition to that under random choice is

$$\frac{2(17+24b+9b^2)}{27(1+b)^2},$$

which exceeds 1 if and only if $b < (12\sqrt{2}-6)/18 \approx .61$.

5. Policies to Reduce Delays in War of Attrition

Standards organizations are very concerned about delays, and try to reduce them.[14] 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 section I describe the application of this idea to a number of policies mean to reduce delay.

Meeting More Often

Committees charged with developing consensus on a standard typically meet only periodically.[15] A natural initiative toward reducing delays is meeting more often. Presumably, this provides more time to work out technical issues. But to the extent that, as in the model, the work is largely bargaining, the time to agreement is determined by screening constraints, and if the flow costs of delay are primarily the loss of benefits from a new

[14] Besen and Farrell (1991) describe competitive pressures that may be part of the motive for these efforts.

[15] For example, in T1, the ANSI-accredited organization for telecommunications standards, "technical subcommittees" "ordinarily meet four times each year" (T1 Manual, June 1994, paragraph 4.1.5.1.)

market, as in the model, then meeting more often is unlikely to cut delays.[16] Indeed, the model above assumes perpetual meetings, but the delays persist.

Meeting more often to develop consensus therefore seems likely to be of limited value. Of course, once consensus is developed, more frequent plenary or official meetings to finish the process can help. For example, until 1989 the ITU would formally approve standards only at plenary meetings held only 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.[17]

As one might expect from this reasoning, it appears that SDOs have had much more success reducing delays in "final processing" than in reaching consensus. For example, in its 1994 *Annual Report* (page 4), the IEC 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 more than 60%."

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 standardization "in advance of the market," before vested interests grow strong. For example,[18]

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[16] Of course, if meeting more often raises the direct flow costs of participation and if that is a significant part of the total costs of disagreement, then the *time* to agreement will indeed fall, although the total *costs imposed on participants by delay* may not. This would best be analyzed in a model in which costs of continuing disagreement are not simply the delay in the benefits of an agreement; David and Monroe (1994b) discuss such a model. Since nonparticipants too are hurt by delays, such a change may be socially valuable. But the 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.

[17] See *e.g.*, B. Crockett, "ITU takes steps to speed up standards process," *Network World*, 9 October 1989, page 30, and "CCITT chief plots changes to speed standards efforts," *Network World*, 25 December 1989, page 19. For some discussion see Besen and Farrell (1991).

[18] "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).

> "Brian Livingston, connectivity specialist for GE Consulting Services and chairman of the micro managers' 486 standardization committee, believes that 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. That's why we formed the 486 committee before the chip was even released.'
>
> "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."

In general 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. It could thus be viewed as a move "towards" random choice, with the benefits and costs of such a move discussed above. It is not clear how to put this formally in the model, however.

Voting Rules to Reduce Power of Vested Interest

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 my model), it at least enables important participants to hold up an agreement if they hope to extract something they prefer. In the IEC, for example, even minor players have sometimes been able to hold up agreement.[19] In response, some standards bodies have introduced provisions defining the (super)majority required to 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") that allows adoption of a standard on a 71-percent weighted majority. Similarly, Besen (1990) discusses voting arrangements in the Telecommunications Technology Committee (TTC), a Japanese telecommunications standards body. 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

[19] Author's interview with Anthony M. Raeburn, Secretaire General, IEC, Geneva, May 1992.

votes."[20] The ITU has a similar voting provision; see, *e.g.*, Besen and Farrell (1991). And the European Communities' Green Paper (1990, paragraph 18) describes how "...in 1987, the internal regulations of CEN/CENELEC were revised at the request of the Commission to permit the adoption and obligatory transposition of European standards by weighted majority vote."

The two-player model above is inadequate to analyze the effects of changes in voting rules, but one would expect that requiring "less" consensus would reduce delays, as David and Monroe (1994a) have argued in a three-player complete-information model. They also suggest that the screening effect (the best quality emerges) would be weakened by relaxing the definition of consensus.

Incomplete Standardization to Sidestep Conflict

In practice, formal standards do not always ensure compatibility: not every two "conforming" products are interoperable. The 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 "options". For instance, Wagner (1990) describes how the IEEE was expected "to abandon efforts to choose between Motif and Open Look" and to "standardize on the common elements of the two rival GUI and windowing systems, then develop a guide for programmers to write applications that can easily migrate from one GUI to another." Sirbu and Zwimpfer (1985) describe how incompatible options were included in the X.25 packet switching standard in order to avoid intractable problems of vested interest (since 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. On the surface, that might seem like a cop-out ..."

The result of such a decision is often called a "model" — an incompletely-specified standard, or a menu of choices. Two products, both of which conform to the standard,

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

may be incompatible if they reflect different choices from the menu. A set of choices is sometimes called a profile, or a strict standard or functional standard. These profiles are typically developed outside the original standards organization: by user groups, by governments, or by other standards organizations. Sometimes, as in ISO, the original organization then "certifies" profiles — an ironic twist.[21]

One might think that including incompatible options vitiates the standardization effort. That would be too harsh a conclusion. 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.[22] And, if the market respects the model, it is often easier, cheaper, and more effective to patch together compatibility through converters within a model than it would be if competing technologies were not constrained by a (nonstrict) standard.[23] For example, since there are economies of scale in providing converters, a full set of converters is more likely to be offered the smaller the variety of standards permitted within the model, and having no model is like having an infinitely permissive model. Thus, a model is an important partial solution to the compatibility problem.

Intellectual Property Rules to Reduce Vested Interest

Many standards bodies have intellectual-property rules specifying that if a proprietary technology is essential in complying with a standard, the owner must agree to license it

[21] 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.

[22] Even in the controversial case of high-definition television (HDTV), I understand that many parameters of a standard have been internationally agreed. Although the remaining conflicts will probably be enough to ensure that receivers cannot be freely traded (this may have been the intention of some countries), the areas of agreement are large enough to make converting and trading programming much easier than it might have been. Indeed, a proposal to construct "open architecture receivers" that would be consistent with a restricted but considerable range of different possible diffusion standards was taken seriously (although finally rejected).

[23] See for instance Wagner (1990).

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."[24] Similarly, the ISO's *Directives* require that if a standard is prepared "in terms which include the use of a patented item," then the patent-holder must promise to "negotiate licences under patent and like rights with applicants throughout the world on reasonable terms and conditions."[25]

Such licensing requirements will reduce the winner's payoff *ex post*, and increase the loser's; they therefore reduce v, and our model indicates that this will reduce delays. The obvious economic concern is whether these rules reduce the incentive to develop a technology in the first place; I address this question next.

6. Effects of v on Incentives to Improve Proposals

Does reducing v reduce the winner's rewards and thus reduce the incentives to produce a good system? Equation (6), which gives a formula for $u'(q)$, tells us something about a firm's incentive to improve (the distribution of) the quality of its proposals. Assuming that the firm's rival cannot observe the firm's quality improvements, it will continue to play the same concession strategy, and (6) 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.[26] Perhaps more intuitively, effort that shifts q up by $\mathrm{d}q$

[24] Appendix I, "ANSI's Patent Policy", in ANSI (1987). 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).

[25] International Organization for Standardization, *Directives*, 1989, Part 2 ("Methodology for the Development of International Standards"), Appendix A.

[26] 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 takes place. Then the gross incentive to increase e is given by the change in its expected payoff,

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

whatever the realization of the random q will have value $\mathrm{E}[u'(q)]\,\mathrm{d}q$. Thus we take $\mathrm{E}[u'(q)]$ as a measure of the incentive to improve quality. In our example, this incentive is

$$I \equiv \mathrm{E}[u'(q)] = \frac{(1+a)^2\ (1+v)}{(a-1)\ (2+v)\ [2+(a-2)(v+2)]}.$$

Higher v raises W (the winner captures a greater fraction of the gains when its system is finally adopted), but this event is delayed longer. In fact,

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

Thus increasing v increases the mean incentive to improve q (*i.e.*, $\mathrm{d}I/\,\mathrm{d}v > 0$) if and only if $v(v+2) < 2/(a-2)$: that is, if v is small enough. We also note that when a is large (a concentrated distribution of quality), increasing v is unlikely to increase quality incentives.

Proposition 5. *Increasing vested interest in the war of attrition increases incentives to improve q only if vested interest is small enough, and if the distribution of quality is diffuse enough (a relatively small).*

I conclude that, to the extent one can judge from a special model, imposing an intellectual-property rule such as the standards organizations use need not reduce participants' incentives to innovate.

Relative Incentives with Random Choice

Consider the corresponding quality incentive facing a predetermined standard-setter, *i.e.*, a firm that knows in advance that its proposal will be adopted. Its payoff is of course simply Wq, so its incentive to increase q slightly is just $W = (v+1)/(v+2)$. The ratio of this to the incentive I for each firm in the war of attrition (derived above) is

$$\frac{I^{\mathrm{RC}}}{I^{\mathrm{WOA}}} = \frac{(a-1)[2+(a-2)(v+2)]}{(a+1)^2}. \tag{12}$$

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

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

For small v, each firm has stronger incentives to innovate under the war of attrition than has a predetermined standard-setter if and only if a is small enough ($a < 6$ approximately). For large v the incentives are stronger for a predetermined standard-setter.

Our other interpretation of "random choice," as a very rough-and-ready choice between systems once they are presented, gives each participant a quality incentive is $\frac{1}{2}W$. Thus each one's incentive, relative to what it would be in the war of attrition, is half of (12). For small v, incentives are greater under the war of attrition (for all a); for large v, they are greater under random choice.

Proposition 6. *For large v, incentives to improve quality are greater under random choice than in the war of attrition. For small v, the war of attrition provides more incentives than does a symmetric random choice; and if in addition a is small enough (the quality distribution is spread out), the war of attrition provides more incentives than a predetermined standard- setter faces.*

7. 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 therefore be poorly served. In this section I use the modeling framework above to think about how users' and participants' interests may differ, and thus where we might be concerned about representation.

In very broad terms, the problem may not be very severe, provided that active participants indeed want a standard. Nonparticipants (users) 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. Thus participants and nonparticipants have similar lists of objectives. However, the tradeoffs among these objectives may differ considerably between users and vendors. 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 we remove the normalization $W + L \equiv 1$ used in discussing participants' incentives above, and where the function $f(\cdot)$ might be nonlinear. Thus the two groups' incentives differ in several possible ways:

Direct Costs

The most obvious asymmetry is the direct costs of the process. The fact that participants bear these costs and nonparticipants do not leads to several possible disagreements. First, there may be a public-good or free-rider problem: if participants' rents are too small, nobody may want to bear the costs of participating, even though a standard would be desirable. Second, 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 will urge more speed. Third, standardizing in advance may increase direct costs, because they are borne earlier, and they are often borne when delay might reveal that there will be no market or that a completely different approach is appropriate; this suggests that if active participants set the rules, they will be biased against working in advance.

In my model I have assumed that the cost of delay is primarily the delay in getting the benefits of a standard. If direct costs are important, a slightly different modeling approach is appropriate, including such costs; David and Monroe (1994b) give such an approach.

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) would 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 the standard. They might perhaps favor a technology that (given its quality) has a demand structure that lets an oligopolistic industry extract a relatively large fraction of the social surplus. They might use the standards process to exclude rent-destroying new technology.

I suspect that such actions, if jointly undertaken in order to increase joint rents, would be regarded in the United States as antitrust violations; in any case, if I am correct that the standards community generally is very apprehensive about antitrust, they would have some motive to steer clear of such acts. Nevertheless, to the extent that active participants choose the rules, some vigilance in this regard is appropriate.

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 have different tradeoffs between quality and speed of the process.[27] For instance, if $f(\cdot)$ is less steep than this, it means that nonparticipants want some standard but do not care very much about its quality, relative to participants' preferences. 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 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.[28]

8. 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

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

[28] 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.

conclusion of Proposition 2: willingness to wait may be imperfectly correlated with quality. For instance, as Katz and Shapiro (1985) showed, the desire for standards is likely to vary with market share; thus those most willing to concede may be the small firms rather than (as in my model) those with mediocre systems.

In cases where vested interest is important, it might be more efficient to stress speed even at the expense of screening for quality — perhaps somehow moving towards a rapid but less careful choice. Tentative calculations suggest that effects on development incentives might even be favorable and would probably not be disastrous.

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 predetermined standard-setter. However, the benefits of this institution are asymmetrically distributed: the standard-setter gains disproportionately.

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