Standards Development Strategies Under Incomplete Information
--Isn't the "Battle of the Sexes" Really a Revelation Game?

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First Version: May 1994
Revised : September 1994
Present Version: December 1994

Prepared for presentation to the Telecommunications Policy Research Conference, held 1-3 October, 1994 at Solomon's Island, Maryland.

The research reported on in this paper was undertaken by the Brunel-Oxford Project on The Political Economy of International Standards Institutions. The work was funded by the Economic and Social Research Council's (U.K.) Programme on Global Economic Institutions (GEI), under ESRC award L120 25 1003. The support of the ESRC and the encouragement of GEI Programme Coordinator David Vines are gratefully acknowledged, as are the facilities provided to the Project's Oxford team by the Oxford Institute of Economics and Statistics, at its site at St. Cross Building, Manor Road, Oxford, OX1 3UL.

1. Introduction and Motivation

Within the past decade the economic significance of the work of national and international standards organizations has begun to be more widely recognized and appreciated, not only by academic and industry analysts who observe these organizations from a vantage point provided by engineering expertise and political theory (see, e.g., Cargill (1989), Weiss and Sirbu (1990), Weiss and Cargill (1992), Weiss (1993), Weiss and Spring (1993)), but also among economists approaching the subject from the industrial organization perspective (see e.g., Farrell and Saloner (1988), Besen (1990), David and Greenstein (1990), Foray et al. (1992), Foray (1993), Greenstein (1992), Lehr (1992), Swann (1992), Farrell (1993), Antonelli (1993), David (1994)).

And, surely, this is as it should be, given the importance and multifaceted nature of these organizations' activities. The formulation and publication of technical standards, the procedures for certifying the conformance of products with such standards, and especially their activities in regard to the development of standards "frameworks" for the "harmonization" of emerging technologies in the information and communications sector -- such as ISDN (Integrated Services Digital Network) and the OSI (Open Systems Interconnection) Reference Model -- have potentially profound and lasting effects in defining national and global markets, structuring international and interregional competition and patterns of trade, and influencing the rate and direction of technological change. It is not too much to say, therefore, that the performance of these standards development organizations and institutions will affect vital infrastructures for the development of the global economy in the coming century. Yet, the organizational mechanisms built upon voluntary participation in "standards committees" increasingly are seen as being as much a part of the contemporary "standardization problem" as of its solution.

With the expansion of the volume of formal standardization activity being carried on by these bodies has come not only an interest in their impacts upon the industries concerned, but criticism of various aspects of their performance. Although many in the standards community contend that, historically, these institutions have worked well enough, others, including some of the technical experts participating in the standards development process, have expressed an array of discontents with the present standardization regime. Excessive delays in the drafting and approval of standards, rising costs of the resources engaged directly and indirectly in support of

their deliberations, needless uncertainties and confusions caused by the multiplicity of organizations asserting "jurisdiction" or self-assigning responsibility for standardization in the same or closely related technical areas, alleged biases and lack of due process in the constitution of standards committees, non-responsiveness to the economic interests of under-represented consumers and users of the technologies in question -- all these recently have been cited as defects of the process (see OTA (1992), Foray et al. (1992)).

This paper addresses what has been the most pervasive theme in the rising chorus of complaints, namely, the causes of the protracted duration of the interval between the assignment of a standards-writing task to one or another of these organization's myriad committees, and the emergence of a set of formally authorized, published recommendations -- if and when the committee deliberations do eventuate in a set of recommendations approved by the organization. The approach taken here is analytical, and aims to extend previous efforts to gain theoretical insights into the determinants of the performance of standards committees by modelling the strategy choices of participants in "anticipatory standardization" committees, and examining the equilibrium outcomes of such behavioral decisions in various economic and institutional settings. Our model of the committee process views anticipatory standards development as involving the exchange of technical information between proponents of alternative system designs that have yet to reach the stage of commercial development, and takes a sponsoring participant's key decision variable to be the time at which it ceases to engage in research and committee deliberations intended to convince the other participant(s) to accept its proposed standard. In the situation where two sponsoring firms are backing competing proposals, a sponsor's decision to withdraw from the cooperative process depends on its relative payoffs from conceding and putting its research and development engineering resources to other (private) uses, continuing to exchange technological information with the opposing sponsor in the committee venue, or having the other participant withdraw its proposal for the standard. Whereas some of these payoffs are determined by mutually observable economic conditions and shared information about the technologies under discussion that render them common knowledge among the participant-sponsors, other payoffs (namely the sponsors' respective opportunity costs) are treated as private knowledge. In addition to the explicit disclosure of technical details as part of the effort of persuasion undertaken within the committee forum, following Farrell (1993), committee

deliberations are seen here also to reveal private information -- through the observable behavior of the sponsors in keeping (rather than ceasing to maintain) their respective proposals under active committee consideration. The decision to withdraw a proposal from committee consideration must be influenced in part by a sponsor's perception of how likely it is that the opposing sponsor-participant would withdraw first, a perception that evolves over time.

In effect, the analysis suggests that withdrawal from the cooperative standards development process ("conceding") could be thought of as tantamount to the irreversible abandonment of one's own sunk costs in the creation of a commercial viable standard; for a firm that intends to maintain a market position as a vendor of some product, it is also a irreversible commitment to invest in producing in conformity with a rival's standard. The rational participant-firm will weigh the immediately realizable private benefits of such actions against the options value of waiting until further information about the dynamic strategy choice of the other participant is revealed (see, e.g., Dixit (1992)).

The paper is organized as follows. Section 2 briefly discusses the nature of the activities undertaken by the committees and working groups of standards development organizations, and (in sub-section 2.1) reviews the thrust of recent comments on the determinants of these institutions performance. A survey of the way standards development by voluntary committees has been treated in previous theoretical analyses (in sub-section 2.2) sets the stage for the presentation, in section 3, of a model of anticipatory standards development involving committee negotiations between two technology sponsors. It is shown (in sub-section 3.1) that it the structure we present can be analyzed in game theoretic terms as an incomplete information war of attrition of the type investigated by Fudenberg and Tirole (1986), for which it is found that there exists a unique, "Bayesian Perfect" equilibrium outcome. Applying results from that analysis, sub-section 3.2 examines the effects of various market and institutional conditions on the probability that the committee will not be able to reach timely agreement on a standard. Particular attention is directed to the influences exercised by economic factors affecting the benefits and costs of the participating sponsors, and of institutionally specified "rules of the (committee) game" with regard to the degree of unanimity required for agreement on recommending a standard, and the retention or attenuation of sponsors' intellectual property rights. Section 4 concludes by noticing several respects in which analysis of this model's

implications might be carried farther than has been possible on this occasion, and points out other respects in which the basic structure of the model would need to be altered in order to do justice to the strategic complexities of voluntary participation in standards development activities and the interrelationship between strategic interactions in the context of committee negotiations and in the context of market competition.

2. Standards Development Committees in Fact and Theory

According to Weiss and Sirbu's (1990) account, a standards committee normally begins its work with a general project description that resembles a product proposal of a manufacturers in some respects. Argumentation and debate in standards committees takes the form of presentations and discussions of these technical proposals, which in some cases have been brought forward by a sponsoring entity but in other cases are designed by working parties of the committee to whom the task has been assigned. In what follows we shall focus the analysis on cases where technologies are brought into the committee which belong to a portfolio of technologies that represent the design approach favored by the sponsoring, or proposing firm, and where alternative proposals brought by different sponsors requires a choice to be made within the committee.[1]

Since proposed technologies must be introduced for committee consideration by means written contributions, sponsoring firms (or coalitions of firms) must be willing to commit resources to supporting research and the formulation of arguments on behalf of their proposed approach. The quality of the research mobilized for such purposes, and the financial resources that a firm is perceived to be able to commit, rather than the sheer number of personnel it sends to committee meetings on a given subject, appear to carry weight in committee deliberations of

[1] Weiss and Sirbu (1990: 113) note that "informal observation of standards committees indicates that most technologies are developed in committees or are adopted without opposition." This appears to be based on the experience of committees deliberating choices in situations where the sponsors already have developed products but are required to relinquish exclusive property rights in any chosen standard. That would make it less likely that a battle would materialize between contending sponsors, and encourage the compromise formulation of a new standard by the committee. In the case of anticipatory standards development with which we are concerned, however, it would seem that more scope exists for persisting disagreements in design approaches, but it would be more satisfactory to have empirical support for proceeding on that presupposition.

this kind, as does the political process skills possessed by the sponsor's representatives.[2] The latter, in turn, are likely to be improved by frequent and intensive participation in standards committee work, but to command respect the political process skills of the firm's representatives must be coupled with technical expertise.

All these considerations speak to the costly nature of participation in the standards development process for firms that are seriously seeking to persuade the committee to adopt their proposals. On the other side of the ledger, firms who send technically qualified personnel to these meetings may expect that they will gain in ways that do not require them to persuading others to accept their technological ideas; anticipatory standards committees offer a legitimate channel through which they can acquire information about the lines of research, and potential product development strategies being pursued by the other sponsoring organizations who participate, as well as sharing in the knowledge generated by others supporting R&D efforts, and disclosed in the course of committee deliberations. As such "information-exchange-benefits" may more than compensate a firm for the direct costs of maintaining credible sponsorship of its own design approach, it seems entirely possible that there could be firms whose alternative uses of their research engineers are not so attractive as to dissuade them from continuing to participate in keeping an anticipatory standards committee active as a monitoring post, even thought they had little prospect of winning outright converts to their preferred ways of doing things.

2.1 Organizational Rules and the Performance of Standards Committees

The widely shared perception among observers in the information and telecommunications industries, that the traditional institutional mechanisms for standards development by committees are failing to deliver "timely standards" to the market, may or may not be justified. But, there has been no shortage of diagnoses of the reasons for this supposed malady, and of proposed remedies for the problem. Chief among these is the attribution of delay and inclusiveness to committee procedures that favor resolution of technical issues by unanimous consensus, and the associated suggestion that majority or super-majority voting procedures would speed the process.

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[2] In most committees, according to Weiss and Sirbu (1990: 130), firms have only one vote, so that sending multiple representatives to influence the outcome of voting would not convey any direct benefits to a sponsor. On the other hand, the size and overall technical preparation of a firm's "team" could affect the persuasiveness of its technological arguments.

But it also has been observed that the open access rules of voluntary standards bodies permit the participation of parties who construe their interests to lie in steadfastly refusing to .agree to any proposal other than those which they sponsor, thereby blocking the issuing of any recommendations.[3]

A rather different approach to the matter sees institutions that once worked well as having been put under increasing strain by transformations that are occurring in the technological and economic environment. Attention has focused, in this connection, upon several profound changes in the economic environment which, it is suggested, have had significant implications for the manner in which standards are set. The pace of technological change within the IT and communications technologies has increased dramatically in recent years, and that, in turn, has increased the flow of work for standards organizations. At the same time, it has also changed the nature of the standards decision. Whereas previously standards institutions sought to rationalize technology that was changing only very slowly, or in a regulated and predictable manner, this is no longer the case. Today it is more frequently the case that interoperability standards are demanded where technologies still are very much in a state of flux.

The changing nature of the standardization process is particularly evident in the growing importance activities concerned with the development of so-called “anticipatory standards,” that is standards set far ahead and intended to guide the emergence of new technologies and products (see Cargill (1989)). Of necessity, such standards development activities must occur well in advance of the markets’ ability to signal the features of products and processes that users will

[3]But the issues of representation and "voice" in these institutions are considerably more complex than this, and require more careful study before importance is assigned to such criticisms. For example, users complain that vendors dominate the standards-writing process, but that may well be the case because they are able and interested in mobilizing research resources and expertise which is persuasive in context of technical committee deliberations, rather than because the organizational rules and procedures are biased (Sirbu and Weiss (1990), OTA (1992), Foray et al.(1992)). Vendors of equipment complain, in turn, that in organizations where participation is open to individual professionals from the engineering community, the standards-writing process is not "accountable to industry". The exclusion of private vendors from some intergovernmental standards bodies, and of small firms, and user representatives from effective participation in the work of voluntary standards-writing associations has raised persisting criticisms of the "fairness" of the process, and reflects perceptions that standards can be used to cartelize markets and entrench the dominance of incumbents. These, however, are issues that will not be considered here.

value, and these exercises in what is tantamount to cooperative R&D are likely to be encumbered by considerable room for persisting uncertainties, disagreements among the participants as to even the broad performance characteristics of the systems they are trying to design (see David and Greenstein (1990), David (1994)).

On this view the increased duration and costs of the work carried on by standards committees is less a reflection of some chronic institutional breakdown or regime disintegration having occurred, and more a matter the inherent difficulties in -- and, to be sure, in some instances calculated resistances to -- adjusting organizational structures and cultures in response to changes in the functional roles that these institutions are expected to fulfill. Certainly one of the problems is that anticipatory standard setting is a comparatively novel activity for the standards organizations, and less experience -- reduced to administrative wisdom -- has been accumulated regarding the management of the process. Discussions of proposals intended to improve the performance of the standards institutions are hampered by the comparative lack of empirical or analytical knowledge about the behaviors of the participants in those activities, by contrast with the mass of anecdotal information and administrative lore concerning the behavior of standards committees tasked to reduce the diversity and increase the interoperability of existing products. Indeed, the most extensive empirical study (Weiss and Sirbu (1990)) made of the factors affecting the technological choices that emerge from voluntary standards committees is one relating to the selection of various computer network technologies in an array of cases where some candidates for the standard already were in existence and had the sponsorship of established vendor-firms.

2.2 Previous Theoretical Analyses

In a pioneering piece of theoretical analysis, Farrell and Saloner (1988) contrast the setting of standards by committees and markets. Two firms propose their own standard, and engage in a sequence of games whose payoff structure resembles the classic “Battle-of-the-Sexes” game: each would like the other to adopt its preferred standard, but they both have low payoffs if they do not agree on adopting one or the other as the standard. The game is one of complete information, in that their preferences and the payoff structure are common knowledge. On this view, the objective of standard-setting is purely the coordination of the firms’ technology choices,

and the analysis considers three mechanisms for arriving a common technology: a market competition process, a committee process, and a hybrid of the two. Each process unfolds over a fixed number of "periods".

In the pure market process, either firm can adopt its own standard unilaterally each period. If only one firm adopts, the other adopts next period, so a bandwagon leads to coordination. However, if both firms adopt simultaneously, they fail to coordinate on a common standard to the detriment of both. Thus, the market game has "Grab-the-Dollar" payoffs. In the pure committee process, there is a fixed deadline by which time an agreement must be reached for coordination to be effective but there is no gain in arriving at an agreement more in advance of that point. In each period when the committee is supposed to meet, the firms announce whether they still insist on their preferred standard, or will concede. If one firm concedes, they agree upon the other firm's standard. If both insist, the game continues another period (unless the deadline has been reached). If both concede, the game also continues.[4] In this case, there is a war of attrition.

Farrell and Saloner also examine a hybrid structure within which firms can act unilaterally to select a technology and market their product, or seek coordination in the committee; in this sequential game, at each (aligned) period a firm can choose either to unilaterally adopt, or to attend a committee meeting. In comparing these three institutions, it is found that the pure committee process achieves better results in terms of coordination than the pure market process, although it takes more round of play to do so. What economic policy significance this has depends, of course, upon what is assumed about the equivalence in real time between a round of market play and a round of committee meetings (see David and Greenstein (1990)). If "a period is a period" the hybrid set-up can be said to out-perform both of the pure mechanisms for coordination, even though Farrell and Saloner note that both the firms involved do better to leave the achievement of coordination to be determined by the flip of a coin.

Farrell (1993) models standard-setting in a committee as a war of attrition in which firms have standards of varying quality. Each of two firms has private information about whether its

[4] This arbitrary assumption is not an essential feature of the model; in a continuous time analogue of the game, the probability of simultaneous concession is zero.

standard is “good” or “bad”. If the committee agrees upon a “good” standard, the payoff of each firm is increased by the same constant. However, a firm prefers its own standard to the other firm’s standard if both are of the same quality. There is no market process in this analysis.

Farrell finds that the war of attrition between firms always selects the better standard, when “good” and “bad” standards are present. This result follows from the willingness of a firm that has drawn a “good” standard to wait longer to concede than a firm that has drawn a “bad” standard. However, viewed as an information-revelation mechanism, the committee process is not optimal. In particular, the firms would prefer *ex ante* to flip a coin.

Farrell, Monroe, and Saloner (1993) address the phenomenon of the multiplication of private standards consortia, especially in the computer and telecommunications industries (see, e.g. Weiss and Cargill (1991), Monroe (1993) for discussion of recent experience), in a model of the strategy choices of firms that form coalitions to support different system standards in product markets characterized by network externalities.[5] The coalitions in the model can be interpreted most naturally as competing standards consortia, but the analysis may also be relevant to the situation of transnational firms that can choose to participate regularly in the activities of one or another of several national or regional standards-writing bodies. In this modelling exercise the firms are assumed to be vendors of a multi-component system, and when a group of firms use a common interface standard, a consumer can mix-and-match their components into a system. Components are otherwise homogeneous products, and firms draw their unit costs for each component from a random distribution.

In the Farrell, Monroe and Saloner (1993) specification, it appears as an aggressive action for a subset of firms to cooperate in forming a standards development group: firms not in the resulting committee deliberations are made worse off. As a result, consortia formation can be a Prisoner’s Dilemma for some distributions of firms’ respective production costs. That is, if firms 1 and 2 form a standards group, firms 3 and 4 have lower profits as a result; if firms 3 and

[5] Foray (1993) and Antonelli (1993) also deal with private (non-institutionalized) standards consortia, or coalitions, making use of some insights from the theory of clubs and models of political "tipping" behavior, but they do not give a rigorous game theoretic treatment of the elements of strategic interdependence that are present when firms are choosing whether or not to join one rather than another coalition.

4 form a standards consortium in response, firms 1 and 2 are worse off as well. For some cost distributions, the negative externality of committee formation to outsiders exceeds the private benefit to insiders, so the ability of firms to enter into such cooperative alliances paradoxically lowers each firm's profits.[6]

If private consortia or regional standards development organization's committees can exclude firms from participation, the process described in the foregoing illustrative case may halt when there are two groups, each comprising two firms. However, if firms cannot be kept from joining coalitions, firm 3 would choose to join firms 1 and 2, and then firm 4 would join the other three, and global harmonization of the industry standards would come about. Nonetheless, for some cost distributions, however, industry-wide standardization results in lower industry profits than when every firm adopts an idiosyncratic and mutually incompatible technology.

2.3 Committees versus Markets -- How Do They Differ?

One question not addressed in these analyses just reviewed is how standards committees differ from markets. In a war of attrition among sponsors of alternative technologies, a firm can withdraw its proposal for an industry standard without attending a committee meeting; in the committee formation game, firms can adopt the same standard in a *de facto* market process without any face-to-face meetings. For instance, firms may standardize on the same shape plug by imitating the plug design used by a dominant firm.

An explanation of why standards committees exist as an institution must address how they differ from *de facto* agreement in the market. Some possible answers are that committees allow firms to make joint commitments, to share information, or to undertake joint tasks. These are discussed in turn below. This discussion might prove useful in further theoretical or empirical work beyond the limited range of analytical questions that can be tackled here.

(a) Commitments:

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[6] It is an interesting question to consider how fully this implication would carry through under the interpretation suggested above, so that the ability of transnational producers of multi-component systems (e.g., telecom equipment) to shop around between different regional standards development bodies such as ETSI in Europe, the T4 Committee of ANSI in the U.S., and the Japanese counterpart organization, might have perverse profit consequences.

By this explanation, committees exist so that firms undertake commitments, perhaps through written contracts. For instance, a firm might promise not to adopt any standard until a given committee deliberation is complete, as in Farrell and Saloner (1988). They might also agree to abide by a voting rule other than unanimous consent. Finally, the committee might offer a firm the means with which to make an irreversible commitment to withdraw its standard. This approach raises the question of why firms have chosen one type of contract rather than another. One can ask what type of contract between firms maximizes their joint profits within constraints such as anti-trust regulation.

(b) Information Sharing:

Firms might also form committees to share information about their technology, their preferences, or about the nature of demand. Once again, the question arises why technology sharing does not take place through arms-length licensing. Committees might be seen as a forum in which buyers of technology join forces to negotiate concessional licensing arrangements with technology suppliers. The buyers might be able to use their monopsony power and the threat of adopting an alternative technology to obtain low-cost or free licenses.

One issue is how firms go about revealing information of their technology to their competitors, when that information might be used against them in the marketplace. Firms have a temptation to hold back their best technology. This problem might be overcome by reputational effects arising from repeated interaction in a standards body.

Standards committees can also allow firms to share information about their preferences in a way they cannot at arms length. Firms may voluntarily adopt a standard agreed upon by a committee that they would not have adopted *ex ante*, if the sharing of preference information raises the probability that other firms will adopt that standard. The willingness of firms to reveal information in a committee might be intensified by the presence of another committee offering a different standard.

(c) Joint Tasks:

A third possible distinction between committees and markets is that firms in committees undertake joint tasks such as R&D, design of standards, evaluation of alternative technologies, promotion, and the development of conformance testing protocols based upon the standards that they produce. Committees may serve as a vehicle for overcoming free-rider problems in the

funding of mutually beneficial activities such as the coordination of legislative lobbying efforts

In the analysis presenting by the following section the model of the strategy choices of a firm with regard to its participation in an anticipatory standards committee (ASC) emphasizes the value participants derive from the open pooling of some kinds of technological knowledge, and supposes that their decisions about whether to go on sponsoring adoption of their preferred technical design approach in that cooperative forum will be influenced by comparisons between the benefits of the knowledge obtained through the joint R&D tasks, on the one hand, and the economic grains they could expect to derive by deploying the same or equivalent technical resources in their own (non-cooperative) R&D programs.

3. Anticipatory Standards Development as a Game of Revelation

The following model addresses some of the issues raised above. It views a committee as a forum for the cooperative exchange of some technological information in anticipation of the actual commercial introduction of alternative product formulations. Participation in this ASC activity as a sponsor of a design approach uses technical resources which have an opportunity cost (C_i) for the i-th firm, but which yield it some immediate net information benefits. The latter can take the form of the technological knowledge disclosed by another sponsor in the course of trying to persuade the committee of the virtues of another design approach. If the reproduction costs of the knowledge exchanged are taken as a measure of its direct value, and the firms have different research capabilities, each sponsor may enjoy a net flow of benefits from the knowledge disclosed (D_i) which constitute the gains from (information) trade. Active participation in the ASC also may convey some reputation benefits upon the firms in their respective current market activities, even if these are technically quite in distinct from and independent of the work carried on in the committee context; sponsorship in this public venue is a credible demonstration of a firm's capability and interest in developing technological products in the future that are in some way complementary with its present product offerings. At any point in time, however, a sponsoring firm can withdraw from this cooperative R&D activity, making what we treat as an irreversible withdrawal of support for its design proposals. In the basic model it is supposed that the anticipatory standards development committee has two firms sponsoring alternative design approaches, and the organizational rules call for committee recommendations to be made by

unanimous agreement. Each sponsoring firm would prefer that the other firm withdrew its proposed technology, so that commercial development could begin on the basis of its own design -- in which it held some competitive production advantages, either in the form of some residual intellectual property rights, or initial cost advantages deriving from familiarity with the design approach. It is supposed, therefore, that from the date at which the flow of benefits from pre-market information disclosures in the committee ceases, the firm whose technology has emerged as the anointed standard begins to enjoy an (augmented) flow of commercial profits (M_i). If the prospect is that this gain would be greater than that derived by the withdrawing firm, the dynamics of the pre-market ASC process -- its aspects of cooperative information sharing within the context of each meeting notwithstanding -- can be seen to have the formal structure of a war of attrition.[7]

Fudenberg and Tirole (1986) have analyzed a continuous time model of a war of attrition involving a pair of firms that embark upon the process with commonly held knowledge about some aspects of the payoff structure, but for which other information pertinent to their respective decisions is privately held. By contrast to mathematical models of wars of attrition under conditions of complete information, the course of play reveals to each player information about its rival that alters it own perceptions about the prospects of winning. Because the initial conditions of uncertainty are such that there is a positive probability that one's rival's dominant strategy would be never to concede, Fudenberg and Tirole's (1986) model has a unique equilibrium, unlike the classic war of attrition.

Although originally cast "A Theory of Exit in Duopoly", Fudenberg and Tirole's (1986) incomplete-information-war-of-attrition results lend themselves to reinterpretation and extension in the context of present interest. The model provides a useful framework in which to assess the effects upon the duration and conclusiveness of anticipatory standards development by committees of an array of structural (including institutionally pre-determined) conditions, such as asymmetries in R&D and production competence among the participating firms, institutional norms regarding retention by sponsors of intellectual property rights in standards recommended

[7] In this respect the model here follows in the tradition of Farrell and Saloner (1988), and Farrell (1993).

by the committee, and other factors bearing upon the payoffs.

3. 1 The Model: An Incomplete Information War of Attrition

In setting out the basic model we are able closely to follow Fudenberg and Tirole's (1986) presentation, even adopting most of their notation, by reinterpreting the action they describe as exit from a market duopoly as the announced withdrawal, by either one or the other sponsor of further support for its proposed technology design the ASC's deliberations, thereby initiating the market implementation phase of the surviving firm's technology.

Assume, then, that among the participants in a newly constituted ASC there are only active two technology-sponsors. Let $D_i(t)$ represent the instantaneous payoff from the committee disclosures of technological information obtained by a sponsor when neither sponsor has withdrawn, and $M_i(t)$ the instantaneous payoff of a sponsor when the other has withdrawn and its own design approach become the standard for market development. Assume the decision of a sponsor to withdraw its proposed standard cannot be reversed. In addition, confine the analysis to situations in which $D_i(t)$ and $M_i(t)$ are non-decreasing in t and converge asymptotically to D_i- and M_i-, respectively. In other words, the underlying pace of technical advance is sufficient to at least maintain the value of the net information benefits sponsoring firms derive from cooperative knowledge pooling in the committee context; and, the stream of profits to be reaped from the point at which a firm becomes sole standard-bearer in the market based on the new technology, likewise is constant or rising over time. These are not unreasonable characterizations of the conditions under which anticipatory standards development activities take place. No less plausibly, it is assumed that a sponsor's payoff will be greater when the other has withdrawn, that is, $M_i(t)>D_i(t)$ for all t. Strictly, it is sufficient to assume something weaker than this, namely, that the present value of the flow $D_i(t)$ from time t onwards is smaller than the present value of the flow $M_i(t)$ from the same date forward. A sponsor that withdraws receives a constant flow payoff of C_i, which is not a function of t.

The firms are risk-neutral and seek the maximize the expected present value of future benefit

streams over an infinite horizon, with discount rate r.[8] We follow Fudenberg and Tirole (1986), further, in assuming that in effect, $D_i(t)$ and $M_i(t)$ are common knowledge; but neither firm knows the other's *opportunity costs*, $C_i(t)$, of making a credible case in support of its proposal in the committee. The level of these opportunity costs is taken to be stationary, $C_i(t) = C_i$. More specifically, firm i's beliefs about C_j are described by a stationary continuous distribution g_i which is positive on support $[C_i\_,C_i\text{-}]$, and the C_i are independent across firms.[9] The densities g_i are continuous and bounded away from 0.

Two additional restrictions are imposed on the domain of the support of g_i, in relation to D_i and M_i. First, we suppose that a firm drawing $C_i\_$ would prefer remaining in a committee deliberation forever to withdrawing immediately. More precisely, defining

$$d_i = r\int_0^\infty e^{-rt} D_i(t)dt$$

it is assumed that $C_i\_ < d_i$. In other words, there is some probability that two standards can coexist indefinitely. Second, a firm drawing $C_i\text{-}$ would prefer withdrawing immediately to remaining in a monopoly forever. More precisely, letting

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[8] It is reasonable to suppose that the participants are aware of the possibility that an exogenous technological advance may occur that would render the work of their particular standards development committee obsolete. We could the possibility of the game being terminated due to that intervening event formally, simply by including as an alternative outcome -- with some positive (conditional) probability given by a non-decreasing hazard rate -- the termination of the $D(t)$ or $M(t)$ benefit streams. As it is easy to show that this would be tantamount to discounting the benefit streams by the hazard rate (obsolescence risk premium) plus the interest rate, it would not affect the basic structure of the model. The implications of interpreting the discount rate in this way will be noted below, however, in sub-section 3.2.

[9] The firms' opportunity costs of devoting R&D resources to preparing presentations to the committee, and the diversion of the time of technical personal to committee participation, depend upon characteristics of the firms (independently), and aspects of their market positions, that plausibly are not directly observable to their rivals. Since C_i is normalized to be time stationary, whereas D_i and M_i are non-decreasing, implicitly the analysis excludes only those cases in which C_i is increasing over time. This last would correspond to the situation where an ASC is working on technologies that are commonly known to be of decreasing commercial promise, as case that is seem entirely reasonable to exclude from consideration.

$$m_i = r\int_0^{\infty} e^{-rt} M_i(t)dt$$

we assume that $m_i < C_i$-. Together the foregoing assumptions imply that $0 < C_i\_ < d_i < m_i < C_i$-.

The strategy of firm i is a function T_i:$[C_i\_, C_i\text{-}] \rightarrow [0, \infty]$, specifying for each possible value of C_i the time at which firm i will discontinue supporting its proposal before the ASC. Since this discontinuation date is the only strategic variable considered, the only information that is revealed (beyond that which was common knowledge as the outset) if a firm is seen to be continuing to support its proposal at time t is that its opportunity cost is not such as would have led it to withdraw earlier. Fudenberg and Tirole (1986) solve essentially this model for Bayesian-Perfect equilibria. In a Bayesian equilibrium, as the game progresses each firm updates its beliefs about the variable that the other firm holds as private information. More specifically, the longer that firm j remains in the game without conceding, the longer firm i expects it to stay within the game.

If we denote by $V_i(t_i, T_j(.), C_i)$ the present value payoff to firm i when firm j's strategy is $T_j(.)$ and its own strategy is to withdraw at time t_i if firm j is still actively sponsoring a rival standard in the committee, then $\{T_1^*(C_1), T_2^*(C_2)\}$ is a Bayesian equilibrium for the pair if at every point $t_i \geq 0$, $V_i(T_j^*(C_i), T_j^*(.), C_i) \geq V_i(t_i, T_j^*(.), C_i)$.

In a war of attrition under conditions of complete information there will be a multiplicity of equilibria, as can be seen by considering that if any firm chooses a strategy of "never withdraw", the other firm's strategy is response is to withdraw immediately. The Fudenberg and Tirole (1986) incomplete information model eliminates those equilibria in which an arbitrary firm selects the strategy "never withdraw", because there is no certainty that the other firm will immediately withdraw in response. Consequently, we can assert for the game under consideration

Property 1: There exists a unique Bayesian Perfect equilibrium (Fudenberg and Tirole).

We can now proceed to examine what conditions affect the identity of the survivor of this

war of attrition, and therefore, the characteristics of the standard that are associated with those of its sponsoring firm. One factor that determines whether a firm wins is the opportunity cost C_i that it draws. Recalling that $T_i(C_i)$ be the time at which a firm drawing C_i abandons its standard, we can say that

Property 2: T_i is nonincreasing in C_i (Fudenberg and Tirole).

This intuitively satisfying result states that firm *i* concedes more quickly when it has a high opportunity cost of staying in the committee negotiation process than when it has a low opportunity cost of remaining active in the committee. The implication, however, is perhaps less satisfying: since C_i is randomly drawn from $g(.)$, nothing guarantees that the firm remaining active is the one whose proposed standard would generate the maximal flow of market returns, M_i, much less than the standard that is socially most beneficial.

To obtain further results, it help to focus first on the case in which firms are symmetric *ex ante*. The firms will have the same functions for $M(.)$, $D(.)$ and $g(.)$, so the subscripts on them are unnecessary. As has been noted, one immediate implication of Property 2, then, is that a firm with higher opportunity cost to participation C_i *ex post* will be first to concede.[10]

It is also possible to obtain *ex ante* comparative statics results. Consider the effects of a policy that increases $M(t)$ for any t. Let the *stalemate date* of a game be the date after which no player would withdraw if both players are still in the game. Then we may state

Property 3: Shifting up the $M(t)$ function postpones the stalemate date (Fudenberg and Tirole).

This property also is intuitively appealing: the more a player has to gain from the other

[10] This is another property of the model which stands in contrast to a stationary, complete information model of a war of attrition. In the latter sort of model, a firm that is going to receive a higher payoff to staying in the game must choose a strategy (say a higher hazard rate for conceding) that will raise the likelihood of it withdrawing sooner, so that, in the unique, stationary, mixed-strategy equilibrium, it remains indifferent between choosing that hazard rate and conceding immediately. Results of the latter kind are presented by David and Monroe (1994) in a complete information war of attrition representation of standards-setting by committees.

conceding, the longer the game lasts. The results of other variations, however, are less straightforward. Shifting up the $D(t)$ function has ambiguous effects on the stalemate date.[11] Increasing probability weight on higher C_i (increasing $g(C)/G(C)$ for each C) *postpones* the stalemate date, rather than advancing it as one might expect.

3.2 Further Analysis

(a) Asymmetries Among Sponsors:

The assumption that players are symmetric is analytically useful, but it prevents consideration of many interesting issues. In practice, participants in standards committees are asymmetric *ex ante*, in ways that are obvious to all. An economic understanding of anticipatory committees therefore calls for deeper analytical insights into which kinds of participant-sponsors tend to prevail and which tend to back down.[12] As that war of attrition can be seen as an all-or-nothing bargaining game, the question may be reformulated thus: What gives a participant-sponsor greater bargaining power?

One insight from the bargaining literature carries over into a war of attrition: size alone conveys no advantage. More precisely, multiplying a player's payoffs in all outcomes by a constant does not alter the players' equilibrium strategies. If firm i's has payoffs $kM_i(t)$, $kD_i(t)$, and distribution function $g_i(kC_i)$, then the value of k is irrelevant to its decision problem. Of course the size of a firm is likely to be correlated with other fixed characteristics that will affect bargaining strength. For example, larger firms typically can finance bigger and more diverse R&D programs, and this is likely to reflect itself in the opportunity costs that they face when it comes to allocating resources in support of the position(s) they take in standards development committees. More generally, it should not be thought that the firm with a stronger bargaining

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[11] But it does unambiguously increase the probability that a player will adopt a strategy of "never concede."

[12] Weiss and Sirbu's (1990) path-breaking empirical study of the attributes of technologies that were selected by standards committees sought to test the predictive power of theoretical insights concerning network externality benefits associated with the products of the sponsoring firms, but these are rather less germane in the context of anticipatory standards development, where the proposals have not reached a stage of commercialization and arguments about compatibility with existing installed base cannot be supposed to carry much weight.

position is necessarily the one that obtains the higher payoff from prevailing in the standards development negotiations.

On the contrary, a player has a strong bargaining position if he does not need to back down. A firm i that draws $C_i<d_i$ will have a dominant strategy of never conceding, so it prefers continuing to conceding, regardless of what strategy the other sponsor chooses. If firm j draws $C_j>d_j$, and believes that $C_i<d_i$, then firm j will concede immediately. For that reason, one could say that firm i has a strong bargaining position if $C_i<d_i$ with arbitrarily high probability, that is, when $1-G(d_i)$ is small.[13] On the other hand, a firm with a weak bargaining position is one that backs down quickly. A firm j that draws opportunity cost $C_j>m_j$ will concede immediately, because it would rather concede immediately even if firm i would concede almost immediately.

Thus, there is a natural classification of participants *ex post* into those which would "always concede," "never concede," or "wait-and-see." Farrell and Saloner (1985) develop a similar classification in a model of rival firms in a market game switching between alternative commercially implemented standards in manipulating their product designs.

Obtaining comparative statics results in terms of these timing strategies is quite straightforward. First, consider the effect of some exogenous market or institutional change which raises $M_i(t)$ for at least some t. Strengthening intellectual property rights allowed the sponsor of the recommended standard might have such an effect, for example. Then, it can be claimed that

Property 4: Any policy that raises $M_i(t)$ for at least some t will increase m_i, and therefore lowers the probability that sponsor i concedes immediately, which is given by $1-G(m_i)$.

Now we may consider a structural change that raises $D_i(t)$ for at least some t. For example, increasing the frequency of committee meetings might have such an effect, if we interpreted the value of technological information disclosed at meetings to be the principal constituent benefits in $D_i(t)$. It can then be asserted that

[13] By assumption, $G(d_i)<1$.

Property 5: Any policy that raises $D_i(t)$ for at least some t will increase d_i, and therefore raises the probability that sponsor i never concedes, which is given by $G(d_i)$.

Committees at work on future systems designs in areas where the underlying technology is subject to radical changes will experience the effects of obsolescence risks on their "performance", in terms of the likely duration of the deliberations preceding the emergence of a recommended standard. Supppose that radical new techniques that reduce to zero the firms' payoffs from the committee standards-writing process, $M_i(t)$ and $D_i(t)$, can be represented as arriving at a time t that is governed by an exponential process having an exogenously determined hazard rate r'. Then, the appropriate rate at which the stream of benefits $M_i(t)$ and $D_i(t)$should be discounted is $(r + r') > r$. We should therefore note that

Property 6: Any policy that raises the (obsolescence) discount rate reduces d_i, and m_i, and therefore lowers the probability that sponsor i never concedes, which is given by $G(d_i)$; whereas it increases the probability that sponsor i concedes immediately, which is given by $1\text{-}G(m_i)$.

Consequently, it would seen that the quickened pace of fundamental technical advance could induce a desire for more frequent cooperative disclosures among ASC participants, and still reduce the probability of protracted committee deliberations for other reasons. This effect, it should be pointed out, runs counter to the oft-voiced presumption that faster technological progress in the fields of computers and telecommunications has overwhelmed the standards development organizations, causing the process of arriving at standards in advance of the market to stretch out further and further. There is not a direct conflict between the latter view of recent experience and the implications derived from Property 5, because the "organizational congestion" hypothesis which underlies it seems to rest on the empirical presupposition that the administrative/managerial capacity of the voluntary standards organizations is fixed -- at least in the intermediate run. Whereas our model does not consider there to be any such constraints on the speed at which the ASC process can proceed.

Finally, suppose a policy increases the probability of firm's having a high opportunity cost

to continuing participation in the cooperation information exchanges that are entailed by the role of ASC sponsorship of a proposed standard. This is tantamount to lowering $G(C_i)$ for all C_i. Weakening intellectual property rights in standards that emerged as recommendations from the committee process, vis-a-vis the level of protection afforded to inventions arising outside the committee context, would tend to have such an effect. We may then state

Property 7: A policy that increases the probability of higher C_i (i.e., lowers $G_i(C_i)$ for all C_i) reduces the probability that a sponsor never concedes, $G_i(d_i)$, and increases the probability that a player concedes immediately, which is given by $1\text{-}G_i(m_i)$.

In other words, a general societal policy tightening intellectual property protection whilst retaining standards development institutions that (for sound enough economic reasons) treat standards as public goods in which private sponsors' property rights should be severely restricted, would tend to shorten standards development proceedings by leading firms to withdraw sooner. This is consistent with the intuition that where spillovers from R&D are large and known, there will be a tendency for private R&D performance to be reduced. Yet, those who would jump to conclude that this problem could be readily corrected by permitting sponsors to retain stronger intellectual property rights in the technologies recommended by ASC's should pause to recall Property 2, above. The effect of such a policy change, in raising the payoff to the survivor of the war of attrition, m_i, would only make matters worse by decreasing the probability of immediate concessions by sponsors of rival technologies in the committee rooms.

Permitting retention of strong intellectual property rights in committee recommended standards would thus appear to be a doubly bad policy from the viewpoint of users of the standards issuing from ASCs; it not only would make access to the emerging standards more costly if and when they do emerge, but, contrary to the folk-wisdom surrounding the advocacy of private incentives to inventive activity, it can actually work to slow the process of generating new standards in advance of the market.

In interpreting Propositions 4-7, one should keep in mind that increasing the probability that one player never concedes (raising d_i) has an ambiguous effect on the length of the game,

as shown by the following two examples. First, suppose the parameters are such that both sponsors would with high probability adopt a "wait-and-see" strategy ($d_k<C_k<m_k$ for $k=i,j$). Then, the game usually lasts a finite, but positive length of time. Suppose d_i increases so that $G_i(d_i)=1$, that is, firm i never concedes for any C_i. In response, firm j will concede immediately for those C_j when he would have chosen the "wait-and-see" strategy before. In these cases, increasing the probability that firm i never concedes makes the game finish immediately.

Increasing d_i can also make the game last longer. Suppose $d_i<C_i<m_i$ with high probability, and that $G_j(d_j)=1$. Because j will never concede, firm i concedes immediately when $d_i<C_i$. Now raise d_i so that $G_i(d_i)=1$. Then both players choose a strategy of "never concede", so the game lasts forever. In the first case, making firm i tougher makes firm j back down, while in the second case, making firm i tougher has no effect on firm j.

It should be noted that the focus of the foregoing analysis on the determinants of dominant strategies of the sponsors makes it quite simple to arrive at comparative statics results, particularly in the asymmetric case. However, it does so by ignoring the class of situations that are indicated in Figure 1 as being those in which committee deliberations take a finite positive length of time, L, to arrive at some resolution. In doing so, it has ignored the nature of strategic interaction and information revelation in those intermediate cases.

(b) Majority Voting:

A war of attrition can be seen as voting contest requiring unanimous approval for victory. We may introduce majority (or other schemes for decision by) voting into the foregoing ASC game, by positing the existence of other members of the committee who are not actively sponsoring their own standards. As a first approximation, suppose the non-sponsors are on average indifferent between the two standards, so either sponsor wins the vote with equal probability. In a more complicated model, the non-sponsors could be of several types: sponsors who have previously withdrawn, vendors of complements, or users, but we ignore these issues for now. We therefore should be concerned to know under what conditions, if any, a sponsor would prefer a vote at the outset, t=0, rather than proceeding to embark upon the usual unanimous consent war of attrition. The following assertion is thus germane:

Property 8: For some functions D_i, M_i, and g_i a sponsor will prefer an immediate vote to unanimous consent *ex post*, whereas for others the same sponsor would prefer the opposite.

Proof. Consider a firm that draws $C_i<d_i$, implying that it will never concede. Suppose it faces a firm j which with arbitrarily high probability draws $C_j>d_j$. Firm j will concede immediately, giving firm i a payoff of m_i/r. One the other hand, firm i's payoff from a coin flip is $(C_i+m_i)/2r$. Because C_i, m_i, and d_i can be chosen independently (subject to the inequality $C_i\_<d_i<m_i<C_i$-), either quantity may be larger. *QED.*

Although Property 8 is stated *ex post*, it extends to the *ex ante* case in a straightforward fashion. This result stands in contrast to the results of Farrell and Saloner (1988) and Farrell (1993) that firms always prefer an immediate coin flip. The contrast can in fact be stated more strongly, as in the following:

Property 9: For any functions M_i, D_i, and g_i, with positive probability there are firms that prefer unanimous consent *ex post*.

Proof. Consider a firm i that draws $C_i>m_i$. In a war of attrition, such a firm will concede immediately, for a payoff of C_i /r. That firm's payoff from a coin flip is $(m_i+C_i)/2r$, which is strictly lower. *QED.*

A coin flip, however, is hardly a compelling model of majority voting behavior. Consider, then, what a more sophisticated representation of the process would look like. Suppose the committee has three rather than two sponsors. Under unanimous consent, two of the three players must concede for a decision to be reached. Under majority voting, only one player needs to concede for a decision to be reached, and that player becomes the swing vote. If it could be shown that Property 2 carries over into a symmetric three player game, then unanimous consent selects the standard sponsored by the firm with the lowest opportunity cost, an outcome that Farrell (1993) found to hold in his two player model.

Under majority voting, fewer concessions are required to reach a decision. David and Monroe (1994) shows that in a complete information model, majority voting concludes more

quickly than unanimous consent. However, majority rule does not necessarily have the desirable selection properties of unanimity. The first player to concede becomes the swing voter, and decides the outcome by choosing to throw his support behind one of the two remaining standards. Information revelation is less complete--only one player reveals his private information about his opportunity cost. Under unanimity, the player with the most "staying power" has the power to set standards, while under majority voting, the swing voter is influential.

Thus, it appears that majority voting is faster, but has lower quality results. This conclusion, however, appears to depends on some strong assumptions. On the one hand, as we have previously observed in regard to the import of Property 2, unanimity produces good decisions only if participants with socially desirable standards also happen to have the most staying power. This happy coincidence could break down on two counts. First, it is not necessarily true that a firm which has a high value to prevailing in a committee contest also has the most staying power. Consider a firm which has a relatively high D_i, so its opponent backs down quickly, but has a relatively low M_i, so it does not care so much about seeing its standard accepted by the industry. Second, a firm with a high value M_i might well have drawn a very high opportunity cost for remaining active as a sponsor, because the success of its R&D independently of the ASC -- say in a patent race -- would be virtually assured by transferring research resources that would otherwise be devoted to supporting its proposal in committee meetings.[14]

On the other hand, majority voting does not necessarily yield socially undesirable decisions. For instance, the swing voter's preferences may be similar to social preferences. There does not seem to be a clear case that either unanimity or majority voting is uniformly superior in its social welfare consequences. Further analytical work is required to delineate the conditions under which one or the other voting procedure is optimal. Issues that deserve closer examination are whether majority voting produces faster decisions in general, how the social

[14] Although there are circumstances under which M_i, could be interpreted as a monopoly return that measured the total producer and consumer surplus, and hence the societal gain from the standard, the firm with the high M_i does not necessarily have the socially most beneficial technology.

desirability of a firm's standard relates to its staying power under unanimity, and which firms self-select into the role of swing voter.

4. Qualifications and Future Extensions -- Interacting Committees and Markets

In the foregoing analysis we have focused upon but one dimension of the performance of standards development organizations, namely, the length of time, and by implication the direct and indirect costs, required for their committee processes to produce new standards for technological systems that have yet to reach commercial introduction. The ASC negotiation game that has been examined is one that is assumed to terminate when only one sponsoring firm remains active in the committee, or when a vote is taken. At that point, and not beforehand, production of the recommended goods embodying the standard is assumed to commence. This is a convenient simplification, for it confines the revelation of private information to those inferences that may be drawn solely from observing firms' participation (or non-participation) as sponsors in the committee context, and not from any actions they might take in market competition. But, clearly, the option of entering the market is one that is open to firms even when they are engaged in standards committee discussions.

Moreover, the behavior of firms in the committee context should reflect what they have come to believe about their rivals on the basis of their market behavior, as well as their committee actions. And *vice versa*. The reality with which we should be concerned in future investigations could be better conceptualized as involving the rival firms in at least two, interdependent wars of attrition, one conducted in the market and the other in the committee room, in the course of which more than one kind of private information would come to be elicited from the participants and would form the basis for the other(s)' strategy decisions.

The functions $M_i(t)$, $D_i(t)$, and $g_i(C_i)$ can be given several alternative interpretations. The assumption that $0<C_{i\_}<d_i$ implies that $D_i(t)>0$ at some point. In other words, if firms receive a flow benefit while participating in committee meetings, this could be taken to refer to a situation where firms are active in the marketplace before the committee arrives at its recommendation of a standard. Thus, the functions $M_i(t)$, $D_i(t)$, and $g_i(C_i)$ embody the payoffs of activity in the market place, in addition to the direct costs and benefits of participation in the committee. These

payoffs may be seen as the reduced form outcomes of complex behavior in the market, such as waiting behavior by consumers, penetration pricing, and so on.

However, the model makes no allowance for strategic interaction between the committee deliberations and the market. That is, firms do not take actions in the market to influence the committee's decision except in a way that can be predicted with certainty at the beginning of the game. On the other hand, a firm's strategy in committee necessarily depends on its payoffs in the market, but a firm knows at the beginning of the game precisely how a decision by the committee will affect its market payoffs at any point in time.

Although the market must become active at some point to have $D_i(t)>0$, a period in which $D_i(t)<0$ can be seen as one of anticipatory standard setting before products reach the market. The model's requirement that the market place potentially opens before the anticipatory standards committee reaches a decision has some realism. Furthermore, this interpretation incorporates the influence of expected market interaction on anticipatory standard setting.

It was suggested above that a shift from unanimity to majority voting increases the role of non-sponsors in the selection of standards. However, non-sponsors do influence the outcome under unanimity through their behavior in the market place, which affects the payoffs of sponsors in committee. Indeed, a sponsor i might withdraw its standard in committee because non-sponsors choose an alternative standard in the market (implying that $m_i<C_i$).

Another direction for further extension of the approach taken here would involve trying to incorporate Farrell's (1993) specification within the framework of Fudenberg and Tirole's (1986) model, possibly by adding the fixed costs of market implementation of the standard by each sponsor to the category of private knowledge, and allowing firms the option of commencing implementation at any point after some fixed date following the initiation of an anticipatory standard development process. That would permit analysis of the performance standards committees in a quality dimension as well as in the dimension of "delivery time" with which the present analysis has been concerned.

References

Besen, S. (1990). "The European Telecommunications Standards Institute," Telecommunications Policy 15 (December).

Besen, Stanley M. and Garth Saloner (1988). "Compatibility Standards and the Market for Telecommunications Services," in R. W. Crandall and K. Flamm, ed., Changing the Rules: Technological Change, Competition and Regulation in Telecommunications, Washington, D.C.: Brookings.

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

David, Paul A. (1994), "Standardization Policies for Network Technologies: The Flux Between Freedom and Order Revisited," in R. Hawkins, R. Mansell and J. Skea, eds., The Politics and Economics of Standards in Natural and Technical Environments, London: E. Elgar.

David, Paul A. and Shane M. Greenstein (1990), "The Economics of Compatibility Standards: An Introduction to Recent Research," Economics of Innovation and New Technology, 1(1&2): 3-42.

David, Paul A. and Hunter K. Monroe (1994), "Voting Rules and the Duration of Standards Development Committee Negotiations: A Three-Player Complete Information War of Attrition," ESRC Project on Political Economy of International Standards Institutions: Research Memorandum 94-01. Oxford Institute of Economics and Statistics. May.

David, Paul A. and W. Edward Steinmueller (1990). "The ISDN Bandwagon is Coming - Who Will Be There to Climb Aboard?", Economics of Innovation and New Technology 1 (1 & 2): 43-62.

Dixit, Avinash. (1992). "Investment and Hysteresis," Journal of Economic Perspectives, 6, 107-32.

Farrell, Joseph (1993). "Choosing the Rules for Formal Standardization," U.C. Berkeley, Department of Economics, Working Paper.

Farrell, Joseph, Hunter K. Monroe, and Garth Saloner (1993) "Systems versus Component Competition: Order Statistics and Compatibility," Working Paper.

Farrell, Joseph and Garth Saloner (1985). "Standardization, Compatibility and Innovation." Rand Journal of Economics 16 (Spring): 70-83.

Farrell, Joseph and Garth Saloner (1988). "Coordination Through Committees and Markets," Rand Journal of Economics 19, Summer.

Fudenberg, Drew and Jean Tirole (1986) "A Theory of Exit in Duopoly," Econometrica, 54, 943-960.

Foray, D. et al (1992). The Role of Users in IT Standardization, ICCP-D5TI, Paris: OECD.

Foray, D. (1993). "The Role of Users in ITS: Meta-Standards, Early Standardization, and the Economics of Coalition." Paper presented to the International Telecommunications Society Conference, Stenungsdaden, Sweden, 20-22 June.

Greenstein, Shane M. (1992), "Invisible Hands and Visible Advisors: An Economic Interpretation of Standardization," Journal of the American Society for Information Science, 43(8).

Greenstein, Shane M. (1993). "Invisible Hands versus Visible Advisors: Coordination Mechanisms in Economic Networks," Faculty Working Paper 93-0111, Political Economy Series #61, Bureau of Economic and Business Research, University of Illinois at Urbana-Champaign, February.

Lehr, William (1992), "Standardization: Understanding the Process," Journal of the American Society for Information Science, 43(8).

Monroe, Hunter (1993) "Mix-and-Match Compatibility and Asymmetric Costs," D.Phil. Thesis, Oxford University.

O.T.A. (1992): U.S. Congress, Office of Technology Assessment, Global Standards: Building Blocks for the Future, TCT-512, Washington D.C.: U.S.G.P.O., March.

Swann, P. (1992). "Standards in ICT: Consensus, Institutions and Markets," Ch. 10 in G. Locksley, ed., The Single European Market and the Information and communications Technologies, London: Belhaven Press.

Figure 1

Dominant Strategies and the Expected Length of the Game, L

C_{j-}	i never concedes, j concedes immediately, $L = 0$	j concedes immediately, $L = 0$	i and j concede immediately, $L = 0$ (war of preemption)
m_j	i never concedes, $0 \leq L \leq \infty$	i and j's strategies depend on parameters, $0 \leq L \leq \infty$	i concedes immediately, $L = 0$
d_j	i and j never concede, $L = \infty$	j never concedes, $0 \leq L \leq \infty$	j never concedes, i concedes immediately, $L = 0$
C_{j-}	C_{i-}	d_i	m_i C_{i-}