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Invisible Hand versus Invisible Advisors: Coordination Mechanisms in Economic Networks

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1. INTRODUCTION

The national information infrastructure today encompasses a broad spectrum of activities. Telephones, automatic-teller machines, computers, the Internet, local area networks (LANs), and supermarket scanners all play a part. It involves both simple and sophisticated equipment -- telephones, wireless communication devices, microprocessors, and thousands of miles of copper and fiber optic lines. Millions of highly skilled professionals maintain and operate this network, regularly modifying and upgrading it, customizing it to millions of uses.

This information infrastructure did not arise overnight, nor did it arise under the guidance of any single policy vision. A host of legal, economic, and historical factors shaped its development over most of this century. The processes were decentralized, usually market oriented, and seemingly too chaotic for any organization to control. Of course, some have tried to control it. AT&T, IBM, the Federal Communications Commission, and the Department of Defense are among those organizations who briefly, and sometimes successfully, coordinated the development of one component of the whole.

There is no single policy vision coordinating infrastructure development today. No centralized decision process could possibly guide such a complex engineering network. By default, decentralized market mechanisms, private firms, and standards development organizations (SDOs) are responsible for many technical standards within the information infrastructure. This state of affairs has grabbed the attention of many industry and academic observers, raising many novel issues. The primary purpose of this essay is to summarize and synthesize for the non-specialist the insights made by economists about the costs and benefits of relying on market-oriented mechanisms for decentralized network development. Economists have been concerned about these issues in the rather recent literature on network economics and standardization. This literature contains many useful insights, but not all of them are consistent with one another, nor do they all transparently synthesize into a single policy vision that is accessible to the non-specialist. Thus, extending this literature with an eye towards synthesis should have some value. A second purpose for this essay is to identify important issues that remain unaddressed and point towards the direction of answers.

Though the article will focus more on the development of interesting insights than the development of management strategies or public policy, I do not intend for this to be an abstract or impractical academic exercise. The paper will focus exclusively on important contemporary events and the development of tomorrow's information infrastructure. Insights about these events should be useful for the development of appropriate public policy and management strategy.

1.1. An overview

The bottom line of this paper is that standardization activity plays a dual role when technical decisions are made by decentralized market-oriented decisionmakers. These dual roles, as a coordinator and a constraint, show up both in short-run and long-run analysis. Analysis engenders so much confusion because both roles are not always recognized. Here is a brief summary of the paper's analysis:

In the short-run, when market structure is relatively stable, standards coordinate contemporary and anticipated market behavior. The costs of using a network of components usually decline because standardization reduces the costs of interconnection. Standards let component designers anticipate interconnection requirements and improve the part of the system in which they specialize. Standards permit system users to make investments in assets and be assured that the assets' value will not depreciate due to loss of connectivity. Yet this coordination benefit is not free. Standards limit the choices of users and vendors. Both users and vendors become locked-in to a set of technical constraints that they may change only at a high cost. Moreover, vendors recognize the strategic importance of locking users to a standard and spend considerable resources on manipulating their development.

In the long-run, the ultimate importance of standardization comes through its impact on technical change. This is because many parts of the information infrastructure have not reached the stasis associated with mature product markets. For example, standardization issues lie at the core of developments in digital cellular telephones, high-definition television, and large local area network communication protocols. In this setting standardization also plays a dual role as a constraint and as a coordinator. As coordinator, stable, functional, predictable standards can aid technical development in most markets. Yet, standards also lock-in users and suppliers. Lock-in is especially costly when technical possibilities change rapidly, removing previous costly technical constraints and imposing others. Thus, standards will constrain technical improvement, but that development will occur sooner and more development will occur along more components.

The analysis first sets the stage with relevant definitions and background. Then it presents a view of the market factors influencing standardization processes in the short-run, i.e., while industry structure is fixed. It follows with an analysis of market factors influencing standardization in the long-run, i.e., while industries evolve. It ends with a discussion of the role of SDOs in the short- and long-run. A short epilogue presents some closing remarks.

1.2. Definitions and distinctions

The difficulty with any analysis is that today's information infrastructure is a "network of networks." It consists of a hodge-podge of public and private telephone networks, the Internet, private LANs and WANs, mainframe and mini computing centers, and numerous communication bridges between various sub-networks. Telephone companies, computer hardware and software companies, satellite operators, the Federal Government, and virtually every user plays some role in this network.

Analysis breaks through this hodge-podge by focusing on one "economic network" at a time. An economic network is composed of all buyers and suppliers who have economic incentive to care about a system's technical features. This concern about technology arises from one of two simple economic factors. Either all users desire to communicate with one another, as in a traditional telephone network, or all users need electronic components to work with each other, as when an industry-wide network of buyers uses the same "standard bundle" -- the minimal set of components necessary to insure system performance.

Notice that the use of "network" here is not conventional (nor will it be throughout this paper). Economists view telecommunications networks as more than just the physical linkages and the electronic signals they comprise, indeed, more than just the physical equipment extant today. Economic relationships extend beyond physical boundaries of equipment. In other words, many buyers and sellers of the same information technology may not buy equipment or services from the same supplier, but they may be a subset of the same economic network if they use compatible equipment. Only when AT&T operated so much of the whole telephone network were the physical network and the economic network virtually synonymous.

All activity in an "economic network" is centered around interoperability: whether a component may serve as a sub-system within a larger arrangement of components. In the simplest case, compatibility-standards can define the physical fit of two components. Familiar examples are modular phone jacks on telephone cords and handsets, and compatible telephone switches. More complex are the standards that determine electronic communication channels. The need for these standards is obvious, since successfully filtering, transmitting and translating signals across telecommunication networks requires precise engineering. Similar needs arise in the design of circuitry between computers, their operating system and application software programs.

More generally, compatibility solves but one issue in a wider array of coordination problems. Most on-line commercial networks, such as Prodigy, Compuserve or America On-line, or the private networks of thousands of commercial organizations and thousands of private firms, are sophisticated electronic networks. These often involve on-line transaction processing, employ a mix of sophisticated telecommunications and computing equipment, and must operate reliably on a daily basis. Accomplishing this involves all the coordination activities associated with the successful management of a business enterprise. Products and services must be defined and tied to billing, output must be controlled and its quality assured, electronic signals must be routed without hesitation and so on. An organization must also plan and develop capital capacity and plan the requisite staffing to meet long run service needs. Sometimes these decisions involve coordinating actions within a single organization. More often then not, they involve coordinating decisions across divisions within the same company, or between upstream and downstream vendors, or between a vendor and a governmental regulator.

Economic research to date focuses primarily on the factors influencing the development of compatibility standards. This focus on the nexus of economics and technology is a bit narrow, since it virtually ignores the important organizational costs just mentioned. Nonetheless, this does not invalidate the merits of the analysis of compatibility, since interoperability is necessary for any coordination on any level. It simply means that standard analysis leaves aside lots of the messy details of coordinating organizations in practice. This review will try to point out where this hole matters and where it does not.

Finally, one other key is the economist's taxonomy of processes that develop standards. Unfettered market processes may develop standards as a *de facto* result of either a "sponsored" or an "unsponsored" market process. In a sponsored process, one or more entities, suppliers, or cooperative ventures, creates inducements for other economic decision-makers to adopt a particular set of technical specifications and become part of an economic network (e.g., pre-divestiture AT&T-sponsored telecommunication standards). An unsponsored process has no identified originator with a proprietary interest, yet follows well-documented specifications (e.g., the QWERTY keyboard). Voluntary industry self-regulation may also play a role when economic networks arise out of the deliberations of SDOs (e.g., IEEE). Of course, government bodies may also shape the development of economic networks (e.g, FCC). This review also try to point out when sponsorship matters and when it does not.

There is no compelling reason for government organizations to become involved in the development of every network. They often do so because important public policy issues are at stake, as when domestic and foreign firms use standardization as a competitive weapon. They often do not do so because exogenous forces, such as dramatic technical change, outstrip the ability of any administrative process to guide events and it may be easier to leave decisions to market participants. The question of when it is best to rely on a market process instead of an government decision making is an open and active topic of debate, since it usually swings on trade-offs between imperfect market processes and imperfect government intervention. This essay will touch on this issue below, but it will not be the primary focus.[1]

Instead, this article will first focus on one part of this debate: understanding the efficacy of relying on decentralized market-based decision making processes and private organizations -- i.e. with minimal government intervention. This is due mostly to space constraints, not any lack of interest. If the reader is interested, several other studies, referenced below, have largely addressed questions regarding government policies.

2. SHORT-RUN ANALYSIS: INVISIBLE HANDS?

Short-run and long-run analysis require different approaches. Short-run analysis presumes that the number of key decision makers (e.g., firms, potential users) is virtually fixed. This is not bad if many rigidities limit how many firms can feasibly produce for a market in the short run -- e.g., a firm's technical expertise, economies of scale, and various other competitive advantages associated with incumbency. By implication, short-run analysis is not appropriate for investigating how technical innovation influences the adoption of standards and the number of suppliers, and vice versa. In addition, since rigidities differ in importance in different markets, the appropriateness of this type of analysis will also differ by industry.

For short-run analysis it is convenient to distinguish between networks in which many suppliers provide related services, a few do, or only one dominates. These distinctions help organize insights about patterns of outcomes and the factors that produce them. Of course, it is not always obvious in practice which markets belong in which categories; Indeed, much controversy is essentially argument over which type of analysis applies to which specific market.

2.1. Diffuse market interests

Standardization may not easily arise when decision-making in a market is diffuse -- i.e., when a market has many buyers and many sellers, none of whom is responsible for a large percentage of economic activity. This is disturbing since diffuse market structures are typically very competitive and tend to allocate scarce resources efficiently through price mechanisms. Many policy issues would be simplified if diffuse market structures gave rise to desirable standards. Figure 1 summarizes the following analysis.

2.1.1. Too many hands and coordination problems

When decision-making is diffuse, the problems that arise are often called "coordination problems." This is not a statement about whether an economic enterprise coordinates its own employees around one objective. The main insight here is that all potential users and suppliers could benefit from as much technical interoperability as possible, but instead tend to go off of their own. The sheer number of decision-makers hinders adequate communication that would render the coordination problems solved. Even if all firms could communicate, differences of opinion make uniform consensus unlikely. Moreover, standards that serve as focal points are unlikely to arise very easily, because every potential supplier and user of a standard is a small part of the whole -- each decision maker has too little incentive to make the investments that will coordinate the design decisions of other users and lead to general interoperability.[2] Thus, due to market structure alone, network growth may be hindered because standardization does not arise, or it arises too late. The proliferation of slightly different Unix systems in the 1970s and 80s is an often cited example.

This observation immediately leads to one disturbing prediction for the growth of private telecommunications networks: if standards are unsponsored then different firm's networks will not likely work with one another without lots of adjustment. That is, private networks often develop according to internal imperatives. When these networks grow larger and brush up against one another, they may be unable to work together for the simple reason that no sponsor insured that they initially developed in a technically compatible manner. For example, after the introduction of the super market scanners it still took many years for suppliers to coordinate their delivery with the inventory management of grocery stores, if they coordinated them at all. Similar factors have slowed the introduction of scanners into the retail clothing sector.

When unsponsored economic networks develop and build capacity, they tend to grow and shrink for many reasons that may have only a minor correspondence with the long-term economic welfare of market participants. This is because standardization processes are often characterized by "bandwagons." For example, networks may be slow to start when they are small and many potential adopters "sit on the fence," waiting to make expensive and unrecoverable investments until a clear technical standard has been chosen by a large portion users. Networks may not develop at all if most participants are "lukewarm" about a new standard due to technical uncertainty, for example, even though all might collectively benefit from it. Alternatively, bandwagons may also grow remarkably quickly once a network's size becomes large enough to justify investments by potential adopters who, in the early phase of development, had delayed making commitments. The lack of communication between all the potentially affected decision makers exacerbates such bandwagons, though professional organizations can often provide communication channels to bridge some of the troubles (see discussion below).

2.1.2. Lock-in: Hand-cuffed by the past?

A very costly problem arises if most vendor and user capacity for a network becomes "locked-in" to a technical alternative, i.e. users and suppliers find it very costly to change fundamental technical specifications. Either hardware or software embodies technical features that cannot be easily changed, or humans cannot be retrained easily to work with a different technology, such as a software interface. These costs are especially high when a network must change (e.g., be upgraded, expanded, or replaced) and the network serves as an essential part of an organization's day to day operations. Change risks significant downtime arising from the costs of fixing the almost inevitable mistakes that any change produces. One recent example was the FAA's attempts in the 1980s to update their air traffic control systems across the country. The small margin for error (and the inevitability that a few mistakes will arise) made the upgrade especially difficult to plan and execute.

Figure 1
Short-run analysis: trade-offs between different market structures

	Unsponsored standard	**Dueling sponsors**	**Single sponsored standard**
Decision making	Diffused to many firms	Concentrated in a few firms	Concentrated in a single firm
Severity of coordination problem	Difficult to reach agreement between all interested vendors and users	Depends on willingness of vendors to design components that mix and match	All decisions internalized by single firm -- depends on management of firm
Pricing	Typically very competitive -- pricing close to cost	Oligopolistic pricing -- typically some markup over cost	Monopolistic pricing -- high markup over cost
Primary distortion	Decisions subject to band-wagons -- Society will not likely get optimal technology	Vendors strategy determine networks -- vendors will lock-in users and lock-out rivals	Monopolist will manipulate technology to own advantage -- blockade as much entry as possible

Lock-in produces two related problems. First, a network may not become as large or as valuable as possible because users lock-in to a disparate variety of formats and each finds it costly to change later. The second problem is related. If many potential adopters wait for a "shake-out," then crucial choices between technologies may be made by early adopters. Thus, early adopters bear a disproportionate influence over standards. Technical designs may not easily be altered to accommodate the different needs of the later decision-makers.

It might be argued that the disproportionate influence of early users is justified because these same users bear a high risk for being intrepid, i.e., their investments in a network can become obsolete or "orphaned."[3] However, this observation does not really address the question of whether society gets an optimal technology or not, which is the central policy issue.

The issue is not solely that the hands of past investment influences future technical choices, which happens quite often and complicates choices, but it is a sober fact of life.[4] Much more of a concern is that society can be "locked-in" to the wrong technology ex post. That is, when viewed with hindsight, "society" could regret previous decisions. This occurs because, to reiterate the point by rephrasing it, even though past choices constrain future choices, future decision makers never have an opportunity to persuade previous decision makers about that choice. Hence, past choices will likely be short-sighted.

The most well known example of this is the QWERTY keyboard, which was explicitly designed to slow down the typists of the 19th century. David[5] argues that the interaction of uncoordinated decisions by typing schools, typewriter manufacturers, and early typists resulted in the adoption of the QWERTY keyboard and its persistence past it useful life. This is especially interesting because a superior alternative exists, yet market participants have never coordinated a switch. A more contemporary example of the lock-in due to intertemporal links is the MS-DOS operating system for PCs. Because it was designed for 8-bit microprocessors, it poorly uses the available RAM on today's 32-bit micro-processors. Similar examples from information technology markets, if perhaps less dramatic than QWERTY, include the development of AM stereo, FM stereo, micro-processor designs, and, as noted, Unix operating systems.

Perhaps the most unsatisfying feature of the analysis of unsponsored networks to date is its use of a stricter concept of irreversibility than is warranted due to the realities of typical technological and economic evolution. Are some features of a technology more mutable than others? Are there degrees of lock-in? Economic analysis has yet to fully understand how these notions can be properly modified for situations where interoperability for components evolve in constant flux, as suppliers update and revise them for applications. Later sections will discuss the growing analysis of converters and options, which partially addresses this issue.

2.2. A few vendors: Hand to hand combat?

Diffuse decision making leads to situations where (1) communication and sponsorship are unlikely and (2) coordination problems are likely. Thus, it would seem to follow that market structures with few vendors may not suffer as much from coordination problems. However, such a conclusion is hasty if it is not qualified properly. In markets with few vendors, the proprietary interests of the vendors leads them to take strategic actions designed to produce outcomes they favor. While this reduces the severity of some types of coordination problems, it instead induces other types of distortions.

The situation that best illustrates these concerns is "dueling sponsors" -- each sponsor has proprietary interests in an array of components that perform similar functions but competitors employ different technical standards. The VHS/Betamax duel in the VCR markets is a well-known and interesting case. Such battles are common today in high-tech industries (IBM v. DEC in minis, MS-Word v. WordPerfect in word processing, FDDI v. ATM in network communications), where the duels may start as multi-firm contests but quickly reduce to a handful of dominant participants. Sometimes a fringe of niche market suppliers follows the leaders, while two or three technical standards dominate all choices. Network duels also commonly arise as sub-plots to related larger product market duels. For example, different banks may belong to incompatible automatic teller machine networks, and United Airlines and American Airlines sponsor different airline reservation systems. If recent experience is any guide, this type of market structure will likely characterize many, if not the majority, of private economic networks in the future information infrastructure.

2.2.1. Problems with dueling

Economists are of two minds about dueling. On the one hand, an important distortion from dueling is that it may prevent the economic network from becoming as large as it possibly could be, even if all users would benefit from a larger network. Unlike an unsponsored network, dueling encourages a vendor to lock-in buyers. This is because dueling sponsors have incentives to design incompatible systems if incompatibility raises the costs to users of switching to a rival sponsor's system. Similarly, the sponsor of a system would like nothing better than to raise the costs to the experienced user from switching vendors, since it makes a user reluctant to change networks.

Vendors like to be the exclusive provider of a technology to a locked-in buyer for several reasons. First, it provides the sponsor with market power during any repeat system purchase. Second, it guarantees a stream of related business. In computing networks, for example, locked-in buyers will purchase CPU upgrades from their system sponsors, and often they continue to purchase a majority of their peripherals and software from the same vendor. Third, locked-in users can be manipulated for competitive advantage. For example, in the case of computer reservation systems, the sponsoring airlines were accused of locking in travel agents and then manipulating the screen to favor the flights of the system sponsor. Similar factors, as well as several pricing issues, prevented automatic teller machine networks from working together as one large network for many years.

Notice that a vendor may desire to lock-in their buyers, but a vendor's competitors will desire the opposite. While a vendor may try to raise the cost of switching, a rival may be working equally hard to lower those costs. From society's standpoint much of this activity is a waste. Wouldn't society be better off if lock-in was just ignored by all competitors and all energy were directed at making better products? Yes, but this will rarely occur because of the strategic importance of standards in a competitive dual.

As with unsponsored economic networks, the market's choice between dueling systems retains the sensitivity to small events, which is some cause for concern[6]. A well-researched example comes from the early history of electrical power supply. Though engineering evidence seems to suggest that alternative current is probably superior to direct current for widespread use, David and Bunn's[7] study shows that many other factors, including "beauty contests" and the decisions of crucial industry participants, such as Edison and Westinghouse, and the character of the gateways between AC and DC, played a crucial role in the success of AC over DC. To appreciate the lengths to which both parties went, consider this example: Edison attempted to persuade the New York state government to use AC in its electrocutions in order to foster the perception that DC, which Edison sponsored, was a safer form of electricity (Incidentally, DC made for more efficient electrocutions, so Edison lost this particular skirmish). In a more current example, Cusumano[8] showed that the development of the VCR standard was sensitive to the relationship of Sony and Hitachi Corporations, the seemingly minor (and temporary) ability of VHS to record longer, and, most crucially, the timing of the introduction of video cassettes, which occurred unexpectedly and rather randomly from the viewpoint of the major VCR manufacturers.

2.2.2. Dueling has its good points

Yet, economists are not uniformly pessimistic about dueling, which is where some confusion arises. Sometimes dueling sponsors will not design incompatible systems. When rival sponsors provide components that perform different functions or complementary functions, compatibility permits many "mix-and-match" possibilities between the components of rival systems. In turn, this raises the profitability of producing compatible components (despite increases in competition). The market for stereo equipment is a familiar example, as is the market for PC hardware clones and software applications under the DOS standard. Thus, dueling sponsors are likely to find it worthwhile to make investments to reduce interoperability costs when they do not produce every type of component, or if each has comparative advantage in the design and production of some but not all components, which is a common occurrence when markets participants have different technical capabilities. This is probably a good explanation for the willingness of many firms, AT&T and IBM increasingly so, to participate in markets with non-proprietary standards.

Dueling standards may also be economically efficient if a variety of standards is appropriate for a variety of potential problems. The crucial question is whether the market will permit entry of a new standard suited to a minority of users; this may depend on the strength of "lock-in" effects or the success of actions of system sponsors to foreclose or induce entry of complementary products, such as software (see discussion below). It is difficult to make any conclusion without careful analysis of particular industries.

Another reason for optimism is that competition and innovation counter balance some of the distortions from lock-in. Monopoly profits may be dissipated through competitive bidding between the rival system sponsors. Since many buyers anticipate that their vendors will later gain monopoly benefits from their exclusive sales of complementary products, they will demand compensation before they commit to investing in network capacity with proprietary features. Such demands can potentially elicit "promotional pricing" from sponsors. The good news is that the networks with long-run economic advantages are likely to provide bigger price discounts. In addition, competitive bidding for new customers may spur incumbent system vendors to innovate. For example, some observers argue that inter-system competition was a primary driver of computer system innovation in the 1960s and 1970s.[9] The bad news is that this benefit sometimes accrues only to new users and not necessarily to users with an installed base of equipment, who are already locked-in.[10]

One other fascinating features of duels is that dueling may induce actions that ultimately lead to the success of one economic network but possibly the loss of the sponsor's control over it. For example, a firm may broadly license a technology to establish it as a standard, but in so doing, sacrifice its control over the standard and much of the monopoly profits associated with that control. Sun Microsystems' liberal licensing strategy, combined with the relatively non-proprietary SPARC architecture, has some of these features.[11]

Another variant of this phenomenon is for a firm to design a product that does no[t] contain proprietary technology. A non-proprietary system induces entry of more periphera[l] and software suppliers and hardware clones. This makes the hardware conforming to th[e] standard more valuable to users, while the entry of more clones reduces the price. Th[e] development of software and peripherals for the IBM-compatible personal computer followe[d] this pattern. Once the standard was widely accepted (partially as a result of all this entry) IBM no longer garnered much of the rent from being the original sponsor of the standard Indeed, today IBM and a consortia of private firms are battling to determine the direction o[f] the next generations of "IBM-compatible" machines. Perhaps the greatest weakness of th[e] economic analysis of dueling systems is also its strength -- the long list of possible outcomes Prediction is quite difficult, particularly in view of the multiplicity of pricing and promotiona[l] strategies typically available to firms in information technology markets. Thus, it is difficul[t] to translate economic analysis into useful managerial advice that is pertinent to more than one specific market.[12]

2.3. Dominance: a strong hand (and maybe even an outstretched arm)

A very natural solution to coordination problems is to place a single sponsor in charge of a standard. All design decisions, upgrading and maintenance problems are internalized within the structure of a single firm. Unifying control within a single firm generally eliminates competing designers and provides users with certainty about who controls the evolution of standards and their ultimate compatibility. This potential benefit from single firm sponsorship cannot be de-emphasized, especially in markets subject to uncertain and rapid changes in technology. Many readers will recognize this as the traditional model of telephone networks under AT&T's pre-divestiture leadership and as IBM's vision for integrating computers and telecommunications under the System Network Architecture (SNA) model. Many other firms have also tried to adopt this model, though competition often forces them into duels.

2.3.1. The problems with dominance

Unfortunately, single firm sponsorship *by a supplier*[13] also brings much baggage with it. There is a general concern that large firms have disproportionate influences upon market processes and they manipulate them to their advantage at the expense of society's long term interests. Most of these concerns arise in the context of anti-trust economics or traditional regulatory economics.

Anti-trust and regulatory issues arise whenever a dominant sponsor competes with small plug-compatible component suppliers in some or all component markets. For example, IBM battled plug-compatible component suppliers from the later 1960s onward. Similarly, from the mid 1950s on (and growing thereafter) AT&T faced competition in customer premise equipment markets and long-distance. And today the Regional Bell Operating Companies are beginning to face competitive bypass to their services from non-regulated suppliers of fiber-optics. Antitrust concerns arise because the dominant firm always wishes to prevent the component firms from gaining market share (and may even want to drive them out of business), while society can possibly benefit from the added competition. Controlling and manipulating technical features of a product, or effectively raising the costs of interconnection, may enhance a dominant firm's strategies aimed at gaining competitive advantage over rivals.[14]

The essence of the problem is that a large system sponsor and small component supplier do not possess the same incentives to be interoperable, i.e., a small firm usually wants interoperability and a large firm does not. The benefits to vendors from accessing a rival network's users is counterbalanced by the loss of market power from facing competition from a rival vendor. Vendors with larger markets are less likely to desire compatibility with smaller rivals (than the smaller rival does with them) because larger firms gain less from selling to a few more customers and potentially lose more from facing more competition. An example of this behavior might be IBM's role in blocking the development of ASCII standards for mainframe computers[15] and allegedly in plug-compatible equipment markets as well.[16]

2.3.2. Dominance and policy issues

There are two difficult issues regarding competitive behavior to address. First, under what conditions will a dominant firm manipulate a technology to its advantage *and* to the detriment of potential entrants and consumers? Second, can and should such behavior be regulated, i.e., are the benefits from preventing inappropriate market conduct greater than the side-effects from imposing an imperfect legal or regulatory rule? Most analysts stumble on the first question, and even if observers clearly describe (in non-polemic language) a sponsor's strategies that are inappropriate for society, they may fail on the second set of issues. Policy rules that prevent inappropriate behavior will almost always also deter perfectly acceptable behavior as well.

As a result, many relevant debates are unresolved. Unresolved debate surrounds any analysis of "leveraging", for example, i.e. using monopoly power in one component market to gain competitive advantage in another. Most economists agree that courts have carelessly applied this concept, though few agree on an appropriate alternative definition. Definitions aside, this issue is fundamental to markets with complementary components. There is no question that a network sponsor can delay entry of complementary component suppliers, and possibly foreclose entry altogether. For example, AT&T's resistance to designing modular telecommunication connections delayed entry of competition for customer premises equipment. However, the unresolved policy question is whether such behavior should be or can be regulated to any good end. One big problem, though not the only one, is that if courts get in the business of second-guessing every innovation, especially those with exclusionary features, it may have a chilling effect on many firm's willingness to introduce any innovation, which normally is not in society's long term interest.[17]

The legacy of the IBM antitrust victories has left firms considerable latitude in the use of standardization for strategic purposes (and potentially exclusionary purposes). However, key legal rulings will probably be further tested by future cases. For example, the recent FTC/DOJ investigation of Microsoft and the recent anti-trust suits against Nintendo foreshadow such a trend. In addition, important legal standards are likely to come from several on-going trials that raise issues in intellectual property rights in computer software standards, and also in trials that attempt to modify Judge Green's restrictions on the Regional Bell Operating Companies.[18] Moreover, legislative attempts to deregulate and foster competition in the telecommunications and cable industries must also confront the same dominance and inter-connection issues.

In sum, there are obvious distortions and biases inherent in having a dominant firm. There are also gains from allowing a single firm to coordinate product characteristics and standards. No consensus on these trade-offs is likely to emerge soon in telecommunications or any other network industry. Issues regarding sponsorship are likely to remain controversial as long as there is no consensus regarding the proper role for monopolies in nascent industries.

3. LONG-RUN ANALYSIS: MAGIC HANDS?

The discussion until now has treated the growth of standards as the byproduct of initial market conditions. This is obviously incomplete for long run analysis: as network industries mature, standardization alters a market's structure. While this feedback is easily recognized, it is not well understood. Usually several factors may be at work at once in the long-run and they may pull/push in opposing directions. Figure 2 summarizes this discussion.

Figure 2
Standardization and technical change: trade-offs between different market structures

	A single firm sponsors a standard	Standards are unsponsored
Systematic innovation	All decisions internalized within single firm -- likely to be accomplished as fast as technically feasible	Firms must coordinate changes within SDOs -- likely to be administratively difficult and slow
Component innovation	Sponsor tends to resist cannibalizing rents on existing products -- component innovation is slow	Component vendors must frequently innovate to stay ahead of the competition -- component innovation is fast
Coordination of technical change	Firm's administrative process coordinates changes in the design of own products	No one is responsible for technical change -- is uncoordinated and uncertain
Degree of lock-in in the long-run	Likely to be high because users have no alternative	Lock-in is as low as possible because competing vendors will try to keep lock-in low.

3.1. Converters: Hands across the water?

Perhaps the most unsatisfying feature of the short-run analysis of economic networks is its use of a strict concept of "lock-in." In most markets, interoperability is in constant flux. The "standard bundle" changes frequently as suppliers update and revise products. Buyers potentially pay enormous costs trying to learn about the new possibilities and trying to integrate components from frequently changing sets of suppliers. The analysis of converters partially addresses this issue.

Converters (or "translators" or "emulators") bridge the gap between otherwise incompatible networks. These products, whether supplied by a system sponsor or third party, reduce the costs of interoperability. For example, a number of third party vendors today supply programs that enable Apple Macintosh computers to use IBM software. As another example, many software programs now come with simple utilities for translating text or data bases from the format of one software package to another. These bridges clearly have value to buyers, so they arise in virtually every economic network (and often "between" networks).

The interesting feature of converters is that vendors unequally share the costs and benefits from their introduction and refinement. Thus, at the very least, the incentives to introduce a converter will probably not match society's. For example, most of the benefits of the IBM/Macintosh converter accrues to users of a Macintosh system, so IBM has little incentive help in its development. Indeed, sometimes a product vendor may actively seek to prevent the entry of gateways and sometimes not, depending on the costs and benefits. For

example, IBM was often accused of discouraging global compatibility between all computer languages.[19]

A related feature of converters is that conditions of competition can shift suddenly and asymmetrically due to their availability. This is because converters may lead to large discreet changes in the boundaries of competition. For example, David and Bunn[20] show that the introduction of the dynamo greatly influenced the AC/DC battle at the turn of the century, tipping the balance irreversibly towards AC.

The economics of converters defies easy analysis because these products are always changing shape and their impact depends on temporary windows of opportunity. In one year a converter may work only at great cost, and in the next the technology may work cheaply. In one year, users may be investing in "anticipatory converters" in order to reduce the costs of a future switch between incompatible standards. In the next a third party may enter with a new product that de facto standardizes switching. In one year, a system supplier may resist the entry of all converters. In the next de facto standards for conversion may be so well defined that no converter is needed any longer. Thus, outcomes and their analysis depend greatly on the context and inherently unpredictable events.

3.2. Technological Innovation and industry evolution

Since so few parts of the information infrastructure have reached the stasis associated with mature product markets, standardization lies at the heart of technical change. For example, standardization issues lie at the core of technical developments in digital cellular telephones, high-definition television, and large local area network communication protocols. However, because standardization may both encourage and discourage innovation in the types of products and organization of the industry, it is difficult to provide unambiguous conclusions.

3.2.1. Does standardization encourage innovation?

On the one hand, well defined technical standards may provide components suppliers a more secure set of interfaces around which to design a product and thus, may encourage research and development into the design of new components for a network. For example, secure telecommunication transmission standards were important in hastening innovation in customer premises markets, such as facsimile machines and modems. More generally, Noam[21] has observed that the success of a communications network sponsor, such as AT&T, comes from developing and standardizing the technology of its network. Ironically, the sponsor's success lays the seeds for later third-party component competition.

On the other hand, an installed base of users may also be an unintended hindrance for innovation on a mature network. An existing substitute network may hinder the growth of a new networks, because the technology embedded in much existing equipment may be inappropriate for a new application, raising its cost. In addition, minority interests may be burdened with higher costs on an existing network, but may not be large enough to justify establishing a new network. For example, Besen[22] argued that the existing AM network hindered the post-WWII growth of the FM network.

Whether or not a network is sponsored or unsponsored, however, network capacity investment decisions determine the ultimate capability of the network. Since vendors often do not have sufficient incentives to embed interoperable technology in their equipment, one can make a case for limited government intervention aimed at guaranteeing a minimal amount of interoperability, at least to induce technical change and capacity investment. This is a frequently used argument for government regulation of electronic protocols in Internet, where there is a fear of widespread technical chaos in the absence of minimal standardization.

3.2.2. Does standardization encourage industry concentration?

Economists are equally ambivalent about the influence of standardization and technical change on a network's market structure. As noted above, the factors producing less concentration are strong: network sponsors may have incentives to license their standard as a means to induce development of new components. In addition, standards may encourage product innovation and new entry by reducing technical uncertainty. For example, the establishment of non-proprietary standards within the PC industry hastened the entry of multitudes of hardware, component and software suppliers, which makes the industry incredibly dynamic and competitive today.

However, the factors leading to greater concentration are equally as strong: buyers often have strong incentives to use a single economic network. If a firm has a proprietary right over the technically superior network technology, then through appropriate strategic actions (and a little luck) the sponsor may be able to mushroom its advantages into dominant control of several technically related market niches. IBM's early success in the mainframe market with the System 360 can be interpreted this way. Similarly, some observers claim that Microsoft is able to use its control of MS-DOS and Windows for advantages in related markets (though the U.S. Department of Justice did not quite make up its mind whether to believe these claims).

3.3. The evolution of the information infrastructure

Economists have intensively studied the long-run evolution of standards in a few industries. Microprocessor markets,[23] computing markets,[24] VCRs,[25] and broadcasting,[26] have sufficiently long and well-documented histories to point toward the following relationships between standardization and industry evolution:

First, different types of sponsorship are appropriate for different types of innovation. If a technology is sponsored by a dominant firm then it is more likely that the sponsor will innovate on a systemic level, i.e. on a level that influences many components at once. Typically systemic innovations are technically complex and more easily coordinated within a single organization. RCA's shepherding of the introduction of color television (through its ownership of NBC) is one example of sponsorship working "well."[27] One drawback to sponsorship, however, is that sponsors of networks tend to resist too much innovation because sponsors do not want to quickly cannibalize their own products, which embody old designs. AT&T's steady, but undramatic, introduction of digital switching equipment is an often-cited example, perhaps rightly or wrongly, for both the good and bad.

In contrast, economic networks with diffuse ownership, where competitive dueling is more common, tend to lead to greater innovation from suppliers of component parts. Component suppliers must cannibalize their own products with new innovative designs just to keep ahead of the competition. One need only examine many information technology markets today to observe this at work. However, diffuse ownership, even combined with established producer groups or standards-writing groups, does not tend to easily lead to systemic innovations, because of the difficulties of coordinating complex technical change across many organizations. Coordinating UNIX standards is an oft-cited example of the latter. In that case, many vendors and public researchers, starting from the same base, each modified the operating system a little bit for their own reasons, effectively balkanizing the UNIX community.

Second, there is a tension between the role of sponsorship in bringing about coordination and in leading to market power. When networks compete, there is a long-run tendency for networks to become less sponsored, because many users resist the market power inherent in such sponsorship. Users choose products with wider supplier bases whenever possible, taking actions to reduce the degree of lock-in. At the same time, many users also strongly desire that at least one market institution take on a central coordination role, which leads them to a dominant firm because a single sponsor can often do a better job at coordinating a network than producer groups or standards-writing groups.

The best example of both these tensions comes from the last thirty years of platform competition in the computing market, where users have gradually been moving from sponsored networks, such as those based on the IBM360/370 mainframe platform or the DEC VAX platform, to non-proprietary PC networks, such as those based on the Intel x86 chip and MS-DOS operating system. Intel and Microsoft have recently been taking on more and more of the functions typically associated with a system sponsor, while so much of the standardization in the peripheral and software market remains non-proprietary.

In any event, prediction about the long-run evolution of an economic network is almost impossible because the success of an economic network is so tied to the success of its underlying technology, which is inherently uncertain (which, of course, does not prevent futuristic technologists from making predictions). Some highly touted technologies gain wide acceptance and some do not, but it is often hard to pinpoint the causes of success or failure. In product markets that regularly undergo radical product innovation, it will not be clear at the outset how valuable a product or service will be, nor what costs each technical alternative may impose on later technical developments, nor how large the network will grow as new applications are developed. As a result, it is difficult to predict a market's dynamics after standardization.

For example, none of the important firms in the VCR industry in the late 1970s anticipated either the consequences for *hardware* competition from the development of the rental movie market, nor the power of the economic links between geographically separate markets. In a more current case, technical uncertainty makes it difficult to predict whether the technical requirements implicit in ISDN will limit or enhance competition. After all, ISDN will influence product design and network growth, which in turn may influence other factors such as tariff structures, network controls, plant investment, and other regulatory decisions.

In sum, the only predictable feature of many information technology networks is that they change. It is not surprising if two snapshots of any particular market niche taken sufficiently far apart in time may reveal different firms, radically different products and applications, and even different buyers. From an individual supplier's or user's perspective, this uncertainty complicates decisions with long-run consequences, since investment in physical equipment is often irreversible and personnel training is expensive in terms of time and money.

3.4. Lock-in and control of technical options.

Most buyers and sellers in an evolving industry know that change will come and that its character will be unpredictable. As a result, most product designers and users of compatibility standards associate potential problems with being locked-in to a narrow technical choice. One of the most interesting and least understood aspects of standardization processes is how attempts to avoid lock-in influences design decisions and market outcomes in dynamic settings.

One approach to understanding standardization activity emphasizes the value decision-makers place on having "strategic flexibility," i.e., having a choice among many future technical options.[28] Its starting premise is that much technology choice involves discontinuous choices among alternatives and an important determinant of an investment is the uncertain revenue stream associated with future technical alternatives. Product designers and technology users will expend resource today in order to not foreclose technical alternatives associated with potentially large revenue streams. The greater the uncertainty at one time, the greater the value placed on keeping technical choices open over time. The value of strategic flexibility may far outweigh the value of any other determinant of technology choice.

Standards may influence firm decisions on whether to design a new product for a given product line, delay introducing a new product, or invest in capacity for an existing product line. A firm may choose to expend extra resources to become part of the largest possible network (by designing a standardized technical platform) because it cannot be certain which of many future designs will best suit its customers. A firm may also expend extra resources to make its products compatible with a mix and match network in order to give buyers assurance that many applications may be available in the future. A firm may hedge its bet by simultaneously employing different technical standards that permit it to reverse its commitment to a technical alternative.

Buyers will also expend resources to leave open options affected by technical uncertainties. Buyers require evidence that their technical options will remain open. For example, the existence of many peripheral component suppliers assures that buyer that an economic network caters to a variety of needs. Alternatively, users may purchase general purpose technologies rather than an application-specific technology as a means to leave open their options for future expansion. For example, Greenstein[29] discussed how federal mainframe computer users in the 1970s telescoped future lock-in problems into the present and made investments in "modular" programming as a result.

Some of this anticipatory activity is in society's interest, but not all of it is. Much of it can be a nuisance and some of it is probably wasteful. From any viewpoint, it is quite frustrating to expend resources on anticipated events that do not necessarily occur. It is also quite easy to be blindsided by events that were not anticipated. This is the aspect of today's network development that many vendors and buyers see day to day, which may be one reason, perhaps, that the absence of standardization is so maligned in trade publications.

4. INVISIBLE ADVISORS: INNOVATION BY ORGANIZATIONS

As noted above, there are many situations in which all component suppliers have an interest in seeing the emergence and the growth of an economic network. Yet, structural impediments may produce coordination problems. The strong mutual interest all firms have in the emergence of an economic network can lead firms to forego market processes and attempt to develop standards in organizations that combine representation from many firms. How do these groups work and do they work well? Do these groups ameliorate some of the problems identified in the short run and long run analysis of unfettered market processes? Figure 3 summarizes the following discussion.

4.1. Consortia and mergers: lending a helping hand?

It seems as if every other day the newspaper announces the formation of another alliance or the merger of erstwhile competitors -- where the participants come together in order to play a large role in the next phase of development of standards for some aspect of the information infrastructure. Though consortia do not have a long and well documented history, a few examples have pointed out some of the economic strengths and pitfalls of developing standards through these groups. Many of the same factors influence the merger of two firms, but this discussion will narrow its focus to only consortia. The reader will easily see the implications for merger.

Figure 3
The economic role of organizations: A comparison

	Consortia	**Standards development organizations**
Motivation for formation	Strategic alliances or outgrowth of joint research venture	Professional societies
Primary benefits	May accelerate development of complementary components	Forum for discussion of issue surrounding anticipatory standards
Main hindrance to success	Strategic interests of vendors override greater interests of organization or society	Strategic interests of vendors override greater interests of organization or society
Coordination of technical change	Will coordinate change only among the subset of cooperating firms	Administrative processes tend to be slow relative to the pace of technical change

Consortia are becoming increasingly popular in information technology industries, partially as an outgrowth of joint research ventures. Most of these groups seem to be concerned with the future of technologies and anticipated changes in related standards. The consortia jointly operates an organization responsible for designing, upgrading, and testing a compatibility standard. The main advantage to consortia is that it allows the firms to legally discuss technical issues of joint interest, while ostensibly avoiding antitrust problems, but retain considerable independence in unrelated facets of their business.

4.1.1. Good points to consortia

The greatest economic benefit of these groups is that they may accelerate development of complementary components. Success is more likely when all the companies (who may directly compete in a particular component market) find a common interest in developing products that complement their competitive offering. Each of the companies may offer different types of engineering expertise, whose full value cannot be realized unless combined with another firm's talents. Each firm may anticipate specializing in one part of the system that the consortia sponsors. In this respect, the incentives for firms to come together in a consortium and jointly design a standardized bundle of components resemble the incentives for several firms to independently produce a "mix-and-match" set of components. However, consortia retain an interesting dynamic element. The consortia help induce other firms to produce complementary components because the consortia's existence act as a guarantee that a standard's integrity will be maintained in the future. Of course, there may still be insufficient investment in complementary products since no producer internalized the entire interest of the network. However, some investment is often better than nothing, which is enough to begin development.

4.1.2. The problems with consortia

Consortia are not a perfect solution to coordination problems. They can easily fall prey to some of the same structural impediments that prevented network development in their absence. The experience with the development of Unix standards in the 1980s amply illustrates these weaknesses.[30] Many firms perceived strategic alliances as tools to further their own economic interests and block unfavorable outcomes. As a result, two different consortia, OSF and Unix International, originally sponsored two different Unix standards. Industry participants lined themselves up behind one or another based on their economic self-interest. More recently, different consortia (and firms) have sponsored slightly different forms of Unix, confusing the market place once again. While two standards (or a few) surely is better than the multiplicity that existed before, there does not seem to be sufficient heterogeneity in user needs to merit two or more standards. Society would probably be better off with one standard, but supplier self-interest will prevent that.

The other potential danger with consortia, as when any group of competing firms cooperate, is that such organizations may further the interests of existing firms, possibly to the detriment of potential entrants or users. For example, consortia may aid collusive activities through joint pricing decisions, or may serve as vehicles to raise entry barriers, chiefly by stifling the development of technology that accommodate development of products that compete with the products of firms inside the consortia. More understanding of consortia will be needed before it is clear whether this is a common practical problem or an unfounded fear. After all, it may be difficult to both credibly invite development of complementary components and deter development of competing components.

4.2. Standards development organizations: A handy alternative?

One of the reasons private consortia are often unnecessary is that other well-established professional organizations serve similar functions. Many large umbrella groups that cut across many industries, such as CCITT, IEEE, and ASTM have a long history of involvement in the development of technical standards.[31] These groups serve as a forum for discussion, development and dissemination of information about standards. In the past, such groups largely codified standards determined by market processes. Today a whole alphabet soup full of groups are involved with anticipating technical change in network industries and guiding their design. Their role in designing "anticipatory" standards takes on special urgency in economic networks in danger of locking-in to technical standards.

4.2.1. Do SDOs work?

Standards development organizations play many useful roles in solving network coordination problems, especially those related to lack of communication. They can serve as a forum for affected parties to educate each other about the common perception of the problems to be solved. They can also serve as a legal means to discuss and plan the development of a network of compatible components, as well as document agreements about the technical specification of a standard and disseminate this information to interested parties.

Perhaps most importantly, SDO standards can serve as a focal point to designers who must choose among many technical solutions when imbedding a standard in a component design. In other words, these groups are most likely to succeed when market participants mutually desire interoperability, need to establish a mechanism for communication and need a mechanism to develop or choose one of many technical alternatives. The involvement of Grocer's groups in the development of bar codes for retail products is an example of this type of situation.

4.2.2. Problems with SDOs

One important feature of most of these organizations is that they are "voluntary."[32] Participating firms and individuals have discretion over the degree of their involvement. In other words, though most firms or individuals belong to the relevant umbrella groups, their contribution of resources (and time) to development can wax or wane for a variety of technical and strategic reasons. This can lead to either extraordinary investment in the process to influence outcomes or to "free-riding" off the activities of the organization. These biases are well-known, and can only be held in check by the professional ethics of the engineers who design standards.

Voluntary standards groups are also no panacea for the structural impediments to network development in some markets. They will fail to produce useful standards when the self-interest of participants prevents it in any event. In other words, designers must have some economic incentives for embedding a technical standard in their product, since use is optional. For example, a dominant firm need not follow the recommendations of a voluntary standardization group. Moreover, it is not likely to do so if it believes that it can block entry and successfully market its products without the standard. IBM's marketing of systems using EBCDIC rather than ASCII, which originated out of an industry group, is one such example.[33]

Similar impasses may occur in a market with dueling technologies, although a voluntary group can play an important role in a duel: if it chooses a particular standard, it could swing the competitive balance in favor of one standard rather than another. However, each sponsoring firm may try to block the endorsement of its rival's standard as a means to prevent this result, which may effectively prevent any standard from being adopted by the voluntary group. The strategies employed in such committee battles can become quite complex, ranging from full cooperation to selective compromise to stonewalling.

SDOs also must battle the perception that they are too slow. No administrative process may be able to guide the development of a network when a slow administrative process cannot keep up with new technical developments. When events become too technically complex and fluid, a focal point is easily lost. For example, this problem is already arising as private telecommunications grow and private groups attempt to coordinate interconnection of their networks based on the ISDN model. One objection to ISDN is that the value from anticipating developments (on such an ambitious scale) is reduced if, as parts of the ISDN standard are written, the character of technology has changed enough to make the standard inadequate. In other words, the standard does not serve as a guide to component designers if the standards organization must frequently append the standard. Since no government administrative process could obviously do any better, market processes will usually predominate instead, coordination problems and all.

Since the decisions of voluntary groups can influence economic outcomes, any interested and organized party will make investments in order to manipulate the process to its advantage. As a result, user interests tend to be systematically unrepresented, since users tend to be diffuse and not technically sophisticated enough to master many issues. In addition, large firms have an advantage in volunteering resources that influence the outcome, such as volunteering trained engineers who will write standards that reflect their employees' interests. Finally, "insiders" have the advantage in manipulating procedural rules, "shopping" between relevant committees and lobbying for their long-term interests.

Committees have their own focus, momentum, and inertia, which will necessarily shape the networks that arise. As a general rule, the consensus rules governing most groups tends to favor backward-looking designs of standards using existing technology. As with consortia, standards may serve as vehicles to raise entry barriers by stifling the development of components from new entrants. The suppliers that dominate standards-writing will want to further the interests of existing firms, not potential entrants or users. These biases are also well-known, and are often held in check by the presence of antitrust lawyers and, once again, the professional ethics of the engineers who design standards.

In sum, voluntary standards organizations can improve outcomes for participants and society, particularly when they make up for the inadequate communication of a diffuse market structure. They are one more avenue through which a system may develop and one more channel through which firms may communicate. They are, however, just a committee, with no power to compel followers. In highly concentrated markets, their functions can be influenced by the narrow self-interest of dueling firms or dominant firms.

5. EPILOGUE

Do decentralized mechanisms lead to appropriate standards? It is difficult to know. Neither blind faith in market processes nor undue pessimism is warranted. Because standards can act as both a coordinator or a constraint, many outcomes are possible. These dual roles of standardization engenders so much confusion, because both roles are not always recognized.

In the short-run, when market structure is relatively stable, standards coordinate contemporary and anticipated market behavior. Standardization reduces the costs of interconnection. Standards let component designers anticipate interconnection requirements. Standards permit system users to make investments in assets and be assured that the asset's value will not depreciate due to loss of connectivity. Yet, both users and vendors become locked-in to a set of technical constraints that they may change only at a high cost. Moreover, vendors recognize the strategic importance of locking users to a standard and spend resources on manipulating their development.

In the long-run, the ultimate importance of standardization comes through its impact on technical change. In this setting standardization also plays a dual role as a constraint and as a coordinator. Predictable standards can aid technical development in most markets. Yet, standards also lock-in users and suppliers. Lock-in is especially costly when technical possibilities change rapidly, removing previous costly technical constraints and imposing others.

In a broader context, the progressive decentralization of decision making in information technologies away from a few sponsors, such as AT&T and IBM, has to be good in the long run. This decentralization unleashed an unmanageable variety of entrepreneurial activity. There is a natural (and sometimes legitimate) desire to want to manage and slow down the massive changes that accompany such entrepreneurial activity. However, such desires should not dictate the pace of change. Dynamism leads to economic growth and development and fantastic technical possibilities. The problems associated with standardization (and its absence) are an unfortunate, but bearable, necessary cost associated with such change.

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ENDNOTES

[1] For more on government regulations of standards see OECD [1991], David and Greenstein [1990], and David and Steinmueller [1992]. See Besen and Johnson [1986] for an emphasis on issues in telecommunications.

[2] At least since the writings of Hemenway [1975], it has been recognized that standards for networks have a "public goods" quality -- i.e., it is difficult to exclude anyone from using a standard and many economic agents can benefit from their use without influencing the costs to anyone else. As is generally the case with public goods, in the absence of actions by government or industry organizations, standards will be underprovided by unrestricted markets.

[3] "In network industries, successful innovations often harm the installed base of a user who bought equipment and training before the new technology was available or recognized as the incipient standard. If I develop a new mousetrap and you choose not to buy it, I have not harmed you. If I develop a new computer operating system, incompatible with the old one you already own, and you choose not to buy it but millions of their users do, then you will find your network benefits much diminished as a consequence of the innovation. This stranding externality has no direct parallel in industries without network effects (Farrell, 1987)."

[4] For example, the installed base of color television sets in the US today all use one set of standards that is incompatible with many of the new high-definition television (HDTV) standards possible. Many observers think it is too costly to abandon this installed base and, thus, recommend using a high-definition standard that is backward compatible with the installed base, even if doing so sacrifices some of the pictorial quality possible with HDTV technologies or raises its cost .

[5] David, Paul A., Clio and the economics of QWERTY, *American Economic Review*, 75, pp. 332-336, May 1985.

[6] It is also the source of considerable intellectual interest. Mathematical models of such processes tend to display highly non-linear results (e.g., see Arthur [1988]).

[7] David, Paul A. and Bunn, Julie Ann, "The economics of gateway technologies and network evolution: Lessons from electrical supply history," *Information Economics and Policy*, 3, 165-202, Fall 1988.

[8] Cusumano, Michael A., Yiorgos Mylondadis, and Richard Rosenbloom, "Strategic Maneuvering and Mass Market Dynamics: The Triumph of VHS over BETA," Working Paper 91-048, Harvard Business School.

[9] Fisher, Franklin M. and McGowan, John J., & Greenwood, Joen E., *Folded, Spindled, and Mutilated: Economic Analysis and U.S. vs. IBM*, Cambridge, MA: MIT Press, 1983.

[10] One critical issue is whether system sponsors can successfully "price-discriminate" -- i.e. identify separate groups of buyers and systematically charge them different prices *and* prevent one group of buyers from selling to the other. If price discrimination is feasible, then only new users benefit from system competition.

[11] However, a sponsor will sometimes give away the standard in the hopes of dominating markets for components later on. Thus, not all monopoly rents are necessarily lost.

[12] Rotemberg, Julio, and Garth Saloner, "Interfirm Cooperation and Collaboration," in Ed. Michael Scott Morton, *Information Technology and Organizational Transformation*, New York: Oxford University Press, 1991.

[13] It is rare, but notable, to observe the opposite, a large buyer acting as a network sponsor. For example, the U.S. Department of Defense has sponsored a network of products using ADA. Another is the GM and Boeing sponsorship of the MAP/TOP standards.

[14] The dominant firm can take actions like "refusing to sell the primary good to a rival; selling only complete systems and not their components; selling both system components but setting high prices for components if purchased separately; 'underpricing' components that compete with those sold by rivals; and 'overpricing' components that are needed by rivals to provide complete systems (Besen and Saloner [1988])."

[15] Brock, Gerald, Competition, Standards, and Self-Regulation in the Computer Industry, in *Regulating the Product: Quality and Variety*, Richard Caves and Marc Roberts (eds.), Cambridge, MA: Ballinger Publishing Co, 1975.

[16] Brock, Gerald, "Dominant firm response to competitive challenge: Peripheral Equipment Manufacturers' Suits against IBM (1979-1983)," in *The Anti-trust Revolution*, J. E. Kwoka and L. J. White (eds.), Glenview, IL: Scott, Foresman, and Co., 1989. Readers also may be tempted to site pre-divestiture AT&T's behavior in the customer premise equipment markets and long-distance markets, but that case is different because of the impact of regulation on AT&T's incentives: Noll, Roger, and Owen, Bruce [1986], "The Anti-Competitive Uses of Regulation: *United States v. AT&T (1982)*," J. E. Kwoka and L. J. White (eds.), Glenview, IL: Scott, Foresman, and Co.

[17] Similar questions permeate debate about whether product innovation in systems of interrelated components is always beneficial or is "predatory" in some sense. Another issue is whether "controlling standards," which various writers define differently, can be used to a controlling firm's benefit at all if competition between systems limits the returns to such behavior.

[18] Also important are many future regulatory decisions regarding interconnection and bypass on local telephone networks, as well as regulatory rules governing private and public boundaries on the data-transmission electronic networks of this country. These rules will arise out of an interdependent mix of FCC decisions, state PUC decisions, Congressional lawmaking, and court decisions. For example, see Kahin [1992].

[19] Brock, Gerald, "Competition, Standards, and Self-Regulation in the Computer Industry," in *Regulating the Product: Quality and Variety*, Richard Caves and Marc Roberts (eds.), Cambridge, MA: Ballinger Publishing Co., 1975.

[20] David, Paul A. and Bunn, Julie Ann, "The economics of gateway technologies and network evolution: Lessons from electrical supply history," *Information Economics and Policy*, 3(Fall), 165-202, 1988.

[21] Noam, Eli. M. "The Tragedy of the Common Network: Theory for the Formation and Breakdown of Public Telecommunications," pp. 51-64 of this volume.

[22] Besen, Stanley M., "AM vs. FM: The Battle of the Bands," mimeo, Santa Monica, CA: The Rand Corporation, 1991.

[23] Wade, James, "Battle of Network Standards: An Empirical Investigation of the Entry Rates of Competing Standards in the Microprocessor Market," mimeo, Walter A. Haas School of Business, University of California at Berkeley, January 1991. Swann, G.M.P., "Product competition in microprocessors," *Journal of Industrial Economics*, XXXIV/1, pp. 33-53, September 1985.

[24] Bresnahan, Timothy, and Greenstein, Shane, "Technological Competition and the Structure of the Computer Industry," CEPR Discussion Paper No. 315, Stanford University, June 1992.

[25] Cusumano, Michael A., Yiorgos Mylondadis, and Richard Rosenbloom, "Strategic Maneuvering and Mass Market Dynamics: The Triumph of VHS over BETA," Working Paper 91-048, Harvard Business School.

[26] Owen, Bruce, and Steven Wildman, *Video Economics*, Harvard University Press: Cambridge, MA. 1992.

[27] The usual consensus is that RCA's technology was as good as society could get. However, it is hard to argue that these events went "well" from CBS's perspective, since they had a competing standard that ultimately lost.

[28] Sanchez, Ron, Strategic Flexibility, Real Options, and Production Strategy, PhD Dissertation, MIT, Cambridge, MA, June 1991.

[29] Greenstein, Shane, "Invisible Hands and Visible Advisors: An Economic Interpretation of Standardization," *Journal of the American Society for Information Science*, 43(8), September. pp. 538-549, 1992.

[30] Saloner, Garth, "The economics of computer interface standardization: the case of UNIX," *Economics of Innovation and New Technology*, 1(1/2), 1, pp. 35-56, 1989.

[31] More than 400 organizations have been estimated to be at work in this country developing, revising, and reviewing standards, though a few groups tend to dominate the development of information technology standards.

[32] The major exception in the United States is when standards written by voluntary standards groups are required by law or administrative fiat, as with building codes. When governments get involved, it is often for the purpose of writing or choosing a standard directly. On occasion government bodies will also rely on those standards determined by an industry umbrella group. See the discussion below.

[33] Note, however, that any advantages IBM accrued were strictly temporary. Bridges between the two standards are common place and virtually costless today. Also see Brock, Gerald, "Competition, Standards, and Self-Regulation in the Computer Industry," in *Regulating the Product: Quality and Variety*, Richard Caves and Marc Roberts (eds.), Cambridge, MA: Ballinger Publishing Co, 1975.

PRIVATE NETWORKS PUBLIC OBJECTIVES
E. Noam and A. NíShúilleabháin (Editors)

Interoperability -- Technical

Standards, Regulations and Private Decisions: A Framework for Analysis

Martin B.H. Weiss

1. INTRODUCTION

In this decade the information technology (IT) industry has witnessed two important trends that have affected the fundamental operation of the industry. On the one hand, the industry standards have increased in number and importance, and on the other, the telecommunications industry, an important sector of the IT industry, was deregulated. These phenomena have similar effects on private decision makers because of their fundamental effects on the marketplace for products and services. In this paper, I propose a single approach that can be used to explain these effects.

The concept of entropy provides a novel framework for analyzing these trends. Deregulation has the effect of increasing the product offerings of a previously regulated industry, resulting in increased consumer choices, whereas voluntary consensus standards have the effect of reducing the number of potential design outcomes.[1] When framed in this way, these two phenomena can be considered simultaneously under the unifying concept of entropy.

In practice, the number of common carrier offerings have flourished under deregulation. As the telecommunications and computer industry have changed, the number of voluntary consensus and *de facto* standards have also increased. In some cases, these standards were substantially competitive with each other,[2] or complimentary to each other.[3] The network managers for private firms have an extraordinary number of choices when constructing private networks under the present circumstances; so many, in fact, that they cannot reasonably optimize the structure of their network. In addition, these choices are changing continuously as carriers offer new services, as new standards emerge, and as firms enter and leave the marketplace. As a result, they frequently choose to set internal standards to complement the body of public standards and regulations that they face.

In the sense of statistical mechanics, entropy can be qualitatively defined to be a representation of the number of ways in which a system can be arranged.[4] Within this construct, deregulation can be seen as a mechanism or phenomenon that *increases* entropy since consumers and producers have more choices. That is, there are more states in which the system can exist. Similarly, standards have the effect of *decreasing* the entropy of the market, since designers and consumers are faced with fewer products and services that can be designed.

It is particularly interesting that these two contradictory trends are occurring in the information technology industry at the same time. The telecommunications policies promulgated by the United States' Federal Communications Commission (FCC) since the lat