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COMPATIBILITY STANDARDS AND THE MARKET FOR TELECOMMUNICATIONS SERVICES

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1. INTRODUCTION

Not so long ago, the determination of technical standards in the United States telephone industry was primarily an internal matter for the American Telephone and Telegraph Company. To be sure, AT&T had to coordinate with foreign telecommunications entities, with independent telephone companies, and with the United States Department of Defense, but the degree of coordination was relatively minor and AT&T had substantial latititude in determining the standards that were employed. However, three forces have caused this situation to change dramatically.

First, because of the entry of large numbers of competing suppliers of equipment and services into the United States telecommunications industry, standard-setting has moved from the technical concern of a single firm to a factor with important implications for competition. As a result, the processes by which standards are set have come to be subject to detailed scrutiny by both the regulatory authorities and the courts. In a sense, telecommunications standards have become too important to leave their determination solely to the telephone companies.

Second, the divestiture of the Bell Operating Companies from AT&T, has, by fragmenting the telephone industry, reduced the ability of AT&T to determine standards as it had in the past. Horwitt (1986, p. 27.) notes that "the market has changed [drastically] since predivestiture days, when Ma Bell set telecommunications standards and other carriers and equipment vendors had no choice but to follow. Now, AT&T is just one more vendor--albeit a formidable one--lobbying for industrywide adoption of the technologies and protocols it wants to use." To an increasing degree, AT&T must accomodate to the choices made by others rather than dictate the standards to which others must conform.

Third, the growing internationalization of telecommunications technology and services has resulted in an increased role for international standard-setting bodies. As a result, the autonomy previously possessed by the United States to set standards has been reduced and the needed degree of coordination with suppliers in other countries has increased. According to Pool (1984, p. 119.), "Until now in the telecommunications field there have generally been two sets of standards, the CCITT standards of the International Telecommunications Union followed in most of the world and the Bell System standards which prevailed in America (about half the world market). In the future...CCITT standards will become more influential in this country, and AT&T will have an incentive to reduce its deviations from them." The major effort presently underway at the International Consultative Committee for Telephone and Telegraph (CCITT) to establish standards for Integrated Services Digital Networks (ISDN), where the United States in only one of a large number of players, is an important indication of this change.

This paper analyzes the processes by which standards are produced in the telecommunications industry, focusing particularly on *voluntary* standards that are established cooperatively and *de facto* standards that are established by the "market." Section 2 considers the forces that determine which process will be used to determine a standard. Section 3 examines cooperative standard-setting in practice. It describes how voluntary standards are set both in the United States and internationally. Section 4 surveys the burgeoning economic literature on non-cooperative standard-setting, i.e., the determination of *de facto* standards. Section 5 considers the impact of standards on competition. Section 6 surveys some recent attempts by the Federal Communications Commission to prevent standards from being used anticompetitively. Section 7 discusses some examples of the processes by which standards are being established in the telecommunications industry and examines the implications of these processes for public policy.

2. THE DETERMINANTS OF THE STANDARD-SETTING PROCESS

There is no standard way in which standards are developed. In some cases, standards are *mandated* by government agencies using administrative processes. In others, *voluntary* standards are established cooperatively, with information being exchanged, technologies being altered, and/or side payments being made to achieve a consensus. Finally, standard-setting may be left to "the market," where *de facto* standards emerge noncooperatively.

Two factors that affect the nature and outcome of the standard-setting process are especially important. The first concerns the private incentives that each of the interested parties--developers, manufacturers, buyers--have to promote the universal adoption of any standard. Such incentives might be low because, even where all parties benefit from the existence of a standard, the private costs of participating in the process by which a standard is adopted may overwhelm the benefits of participating. This is especially likely to be the case for the establishment of systems of weights and measures, e.g., the metric system, and standards relating to the use of common terminologies.

The incentive to promote standards may also be low when standardization eliminates a competitive advantage and this swamps the benefits of having a standard. For example, Brock (1975) reports that IBM was unwilling to accept the COBOL-60 specifications for its business language because it wished to prevent the competition to which it would be exposed if there were a common business language. More recently, Horwitt (1987b) reports that American computer vendors like IBM and telecommunications carriers like Telenet are reluctant to adopt the CCITT X.400 electronic mail standard. Although adoption of the standard would permit communication between subscribers to different electronic mail systems, it would also permit subscribers to move easily from one vendor to another.[1]

At the opposite extreme are cases in which the expected gains to all parties from promoting the universal adoption of a standard exceed the costs they incur from doing so. For example, Hemenway (1975, pp. 13ff.) discusses how the early automobile industry was plagued by incompatibility problems. All manufacturers stood to gain greatly if standards were established and the participation of all was required if standardization was to be achieved. As a result, all were willing to incur the costs of participation.[2]

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[1] By contrast, in Europe the strong demand for X.400 products has apparently forced U.S. vendors to support the standard in order to participate in the electronic mail market.

[2]If everyone benefits from having a standard, but the benefits are unequally distributed, those who obtain the largest benefits may be willing to incur the costs of setting standards while those with smaller benefits "free ride". This outcome, in which a public good is provided by those users who receive the largest benefits, has been referred to as "the exploitation of the great by the small." See Olson (1965) for a discussion of this issue. Olson discusses, among other examples, the case of international alliances in which large countries often pay a disproportionate share of the costs.

The second factor affecting the way standards are set is the extent to which the interested parties have different views about which standard should be chosen. Differences in preferences are especially *unlikely* when there are no important differences among technologies, so that what is important is only that a standard be chosen, not what the standard is. Time keeping and the use of calendars may be examples where no individual cares which system is chosen so long as there is some generally accepted method.[3] Moreover, even when there are differences among technologies, so that the parties are not indifferent among them, the same technology may still be everyone's preferred standard.

On the other hand, agents frequently differ in the standards that they prefer. For example, manufacturers of VHS and Beta videocassette recorders would have different preferences as to which technology was adopted if standardization were attempted. Similarly, computer manufacturers who have designed their machines to work with specific operating systems would prefer different systems as the industry standard. Still another example is that some users of videotex prefer the North American Presentation Level Protocol Syntax (NAPLPS), with its sophisticated graphics capability, while other are content with the less expensive text-only ASCII standard. (Besen and Johnson (1986, pp. 80-84.)[4]

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[3]The hour has not always been of fixed length. At one time, day and night were each defined to have twelve hours. As a result, the length of an hour fluctuated over the year. See Hemenway, (1975, p. 5.) Similarly, many types of calendars have been used throughout history; see *Collier's Encyclopedia*, New York: Macmillan, 1979, Volume 5, pp. 136-145.

[4]In many cases, even if agents have no preferences when a technology is first introduced, they may develop preferences once they

Where preferences differ, each party will promote as the standard the technology that maximizes its private benefits, not the one that maximizes total benefits.[5] In these cases, standard-setting can no longer be viewed solely as a search for the technically best standard, or even as a process for establishing one of a number of "equivalent" technologies as the standard. Instead, standard-setting is a form of competition in which firms seek to gain advantages over their rivals.

We can now identify four cases that differ in whether the interest in promoting any universal standard is large or small and in whether preferences are similar or diverse. The case in which there is a large interest in promoting a universal standard and preferences are similar is what can be called the *Pure Coordination Case*. Here, either there are a number of possible standards among which everyone is indifferent, or the same technology is preferred by all, and the *per capita* rewards to participation in standard setting are large enough to induce everyone to participate. The standardization process is simply a matter of agreeing on which alternative to use. The agreement, once it is

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have adopted a particular technology. Thus, while it makes little difference in principle whether cars drive on the left- or right-hand side of the road, once a convention has been adopted, owners of automobiles and operators of trams or buses will usually favor the status quo. When Sweden decided to switch from the left-to the right-hand side of the road in the late 1960's, a national referendum voted overwhelmingly against the change. (Kindleberger (1983, p. 389). Similarly, owners of railroads with incompatible guages will each have a preference for the guage used by their rolling stock. In the case of railroads, another interested group was workers who where employed to change the settings of the wheels of the rolling stock as it passed from one guage to another. Their interests were in opposing any standardization, since their jobs were at stake. (Nesmith (1985)). This suggests that instances in which agents are indifferent may be rare once there is a substantial installed based of equipment.

[5]This assumes that side payments are not possible.

reached, is self-enforcing since no party has an incentive to deviate unilaterally. In the language of game theory, there are either multiple equilibria with identical payoffs or a unique equilibrium that is Pareto superior to all others. The standardization process serves to select an, or the, equilibrium.

Much standardization is very close to the Pure Coordination Case. While there may be some differences in preferences, these differences are small relative to the gains from achieving standardization. Here, standard setting is likely to be seen as an activity in which experts seek the best technical solution or, at least, choose a standard from a number that are equally good. In short, standard setting is a game in which everyone obtains a positive payoff and, moreover, it is one in which the choice that maximizes the payoff to any party maximizes the payoffs to all others. This view dominates descriptions of the standard-setting process that are produced by standard-setting organizations.

Even where preferences do not differ, however, standardization achieved through private voluntary agreement may not occur. The reason is that the gains to any party may be so small relative to the cost of participation in standard-setting that "free riding" on the part of everyone results in no standard at all. In what might be called the *Pure Public Goods Case*, the *per capita* gain from standardization is too small for anyone to find it worthwhile to participate in the process. Although everyone desires that standardization be achieved, and differences in preferences are small, no agent has a sufficiently large interest to develop the standard. This outcome is especially likely in industries that are highly fragmented, or where the beneficiary of standardization is the public at large. Here, if standardization is achieved it is likely to require government intervention, as in the establishment of standards for weights and measures, time, and language. Alternatively, several incompatible technologies may exist simultaneously.[6]

A third case involves large differences in preferences and little incentive to promote the adoption of a universal standard.[7] In the *Pure Private Goods Case*, if there is no dominant firm, standardization cannot be expected to be achieved voluntarily. Here, private parties would not promote the creation of a formal standard-setting body and, if such a body were established, the objectives of participation would be to promote a favored candidate as the standard or to prevent the adoption of another. Unless side payments are possible, the most likely result is "stalemate," with no party being willing to adopt the technology preferred by others. Participants in standards meetings may attempt to stall the proceedings by, for example, continually introducing new proposals and providing other participants insufficient time to analyze them. The outcome will be either simultaneous use of incompatible technologies, the selection of a *de facto* standard through the market, or the failure of the technology to develop because of the absence of a standard.

Although, in principle, government intervention can break a stalemate, such intervention may itself be the object of controversy, so

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[6]Paradoxically, where standardization cannot create a competitive advantage, so that achieving a consensus should be easy, the incentive to free ride is greatest.

[7]This does not mean that there are no benefits from standardization but only that the distribution of benefits is very sensitive to the standard that is chosen.

that the government may be reluctant to intervene. The stalemate might also be broken if there is a dominant firm. However, if the dominant firm is opposed to universal standardization, it will be a *Reluctant Leader* and may attempt to prevent its rivals from producing compatible products.[8]

A firm with a large market share may be reluctant to promote its technology as an industry standard if it fears that the demand for the products of its rivals will increase at its expense if they can offer compatible products. For example, recently it was reported (Ryan (1987) that Ashton-Tate has attempted to prevent the adoption of its Dbase language as an industry standard. Ed Esber, the firm's chairman, is quoted as stating that: "The Dbase standard belongs to Ashton-Tate and Ashton-Tate intends to vigorously protect it. It's proprietary technology." The argument is that Ashton-Tate's large market share makes it less concerned about the benefits of compatibility than are its rivals.

Another possible example of reluctant leadership occurs where the dominant firm is dominant because it controls access to an input that its rivals need to market either complete systems or individual components. Under certain circumstances, such a firm may prefer that its rivals be unable to offer components that are compatible with its "essential" input. The argument that IBM attempted to make it difficult for competing manufacturers of peripheral equipment to offer products that were compatible with IBM's mainframes was an important element of

[8]See Braunstein and White (1985) for a discussion of allegedly anticompetitive standards practices in the computer, photography, and telecommunications industries.

the government's case in the antitrust suit against the company. A similar argument was made in the government's suit leading to the divesititure of the Bell Operating Companies from AT&T, where the essential input was access to the local distribution facilities of the operating companies.

In the fourth case, there are large differences in preferences and each of the interested parties has a large interest in promoting the universal adoption of a standard. In this *Conflict* case, a dominant firm may, if it desires, attempt to establish a *de facto* standard. Here, the dominant firm will be a *Cheerful Leader* and other firms may be forced to adopt the technology that it prefers. This is apparently what occurred in the emergence of the IBM personal computer as an industry standard.

In the absence of a dominant firm, the interested parties will all participate eagerly in the standardization process. The process can be expected to involve side payments and coalition formation. For example, Horwitt (1987a, p.6) reports that a number of computer software and hardware vendors recently agreed "to surrender market dominance based on proprietary products in favor of a standardized, public-domain Unix environment...One major thrust behind the standards is vendors' realization that a fragmented Unix cannot effectively compete in the mid-range system against emerging proprietary products from the likes of Digital Equipment Corp. and IBM...." The vendors were reported as "willing to cooperate with their competitors - or even adopt a competing product - in order to hasten commercial availability of the multivendor programming and networking products that their customers demand...." Similarly, all major European equipment manufacturers, together with

Digital Equipment and Sperry, have formed the X/Open Group to promote a standardized version of the Unix operating system. Their objective is to permit the portability of applications software among computers made by different manufacturers in order to "preempt any attempt by IBM to establish de facto minicomputer standards, as it has for mainframes and personal computers." (Gallagher (1986), p. 121.)

Firms can also be expected to promote their own products in the market during the standardization process in order to make more credible a threat to "go it alone." They may also attempt to employ the government to increase their leverage either in the market or in cooperative standard setting.[9] However, there will be considerable pressure for a standard to be adopted.

The above four-way classification of the standards process is summarized in Figure 1:[10]

As we have noted above, when standard-setting bodies describe their activities, they typically characterize them as involving Pure Coordination. In these descriptions, the participants are willing to expend considerable resources to achieve compatibility and any conflicts

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[9]The case of AM stereo may be apposite. After the FCC decided not to adopt a standard but to leave leave standard-setting to "the market," some of the contenders succeeded in having the FCC revoke Harris' type-acceptance. This forced Harris temporarily to withdraw from competition and stations using its system to cease operating in stereo, an example of the use of governmental processes to gain a competitive advantage. Later, Harris, dropped out of the competition and stations using its technology switched to using Motorola's, an example of coalition formation. See Besen and Johnson (1986) for a fuller account.

[10]Note that all firms in an industry may not be in the same cell. The examples of dBase and Unix discussed above are apparently cases in which the dominant firm prefers that no standard be adopted, because it thereby retains a competitive advantage, and smaller firms prefer that a standard be chosen, because that enhances their ability to compete.

CONFLICT (VHS vs. Beta)	PRIVATE GOODS (Ashton-Tate)	HIGH	VESTED INTEREST IN A PARTICULAR STANDARD
COORDINATION (Automobiles)	PUBLIC GOODS (Time)	LOW	
HIGH	LOW		

INTEREST IN PROMOTING THE UNIVERSAL ADOPTION
OF ANY STANDARD

Fig. 1--The determinants of the nature of the standards process
(Examples in parentheses)

about what the standard should be reflect differences in technical judgments. Although standardization may not come easily in these cases, standard-setting bodies will generally be able to achieve the needed degree of coordination. At the same time, the conventional description of standard-setting fails to encompass a large and important number of cases in which differences about what the industry standard should be are not primarily technical -- the Conflict case -- or where some of the parties actually prefer incompatibility -- the Private Goods case. We focus in much of the remainder of the paper on situations in which the interests of the parties are not necessarily congruent because they raise the most interesting and difficult standardization issues from the point of view of public policy. In doing so, however, we do not mean to suggest that the Pure Coordination Case is unimportant and, indeed, we provide a detailed analysis of the possible role for cooperative standard-setting in this Case.

Whether consensus will be achieved in private cooperative standard-setting depends on a number of factors including: (a) the importance of the benefits of standardization, (b) whether a small number of participants can prevent an effective standard from emerging;[11] (c) the extent to which the interests of the participants diverge; and (d) whether side payments are possible.

The prospect of achieving consensus is greater the greater are the benefits from the network externalities that standardization produces. At one extreme, if consumers are reluctant to purchase a good from any vendor because they fear that they may be "stranded" with the wrong technology, all vendors have a strong interest in agreeing on a standard. In such cases, firms may be willing to agree to conform to a standard that is not the one they prefer if the alternative is to have no sales at all. On the other hand, the greater the ability of a firm to have sales even where there are no compatible products, the more reluctant it will be to conform to a standard other than the one it prefers.

If the success of a standard depends on obtaining agreement from all participants, standardization is less likely than where a smaller majority is required. Where unanimity is required, any participant can "hold out," refusing to support a standard unless he obtains a large share of the resulting benefits. This can involve either insistence

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[11]This can arise either where all participants want a standard but differ strongly as to what that standard should be, or where some participants do not want any standard to emerge at all. In the latter case, those firms that do not want a standard will not participate in the process, as apparently occurred in the case of the COBOL and dBase standards noted above.

that his preferred technology be chosen as the standard or a demand for payment in some other form. Since all participants can behave in this manner, consensus is unlikely. This may explain why standard-setting bodies typically require less than unanimous consent for a standard to be adopted.[12]

Clearly, the more divergent are the interests of the participants, the less likely it is that a consensus will emerge. Where preferences are similar, the process of standardization involves only learning that this is the case.[13] Once everyone knows that everyone else prefers the same technology, each can proceed to adopt the technology in complete confidence that his behavior will be emulated. Here, information sharing can promote the adoption of a standard that otherwise would not emerge. By contrast, where preferences diverge, not only will such confidence be lacking but each participant will tend to exaggerate the differences in order to have his technology chosen. Thus, each participant may contend that he will not follow the lead of another even if, in fact, he would. The result is to reduce the likelihood that anyone will attempt to start a "bandwagon."

Finally, the ability to make side payments may overcome what otherwise would be resistance to agreement on a standard. Especially

[12]Where less than unanimity is required, a small number of firms may agree to support a standard, leaving to others the decision as to whether to conform. Recently, a number of computer and hardware manufacturers, not including IBM, discussed the creation of a standard for extending the bus for the IBM PC AT from 16 to 32 bits. See "Inside the IBM PCs, Editorial, *Byte*, 1986 Extra Edition, p. 6, 8. Section 3 discusses the rules relating to the adoption of voluntary standards by committees.

[13]See Farrell and Saloner (1985), discussed below, for an analysis of the role of information in standard-setting.

where the difficulty in reaching agreement results from large divergences in preferences, if those who gain most from the standard that is adopted share those gains with others, the reluctance to conform may be overcome. The sharing of gains need not involve cash transfers but could, for example, require that the "winners" license their technologies on favorable terms to the "losers."[14]

3. COOPERATIVE STANDARD-SETTING IN PRACTICE

The analysis in the previous section suggests that there are a wide variety of circumstances in which cooperative standard setting is viable and productive. In fact, an important response to the need for coordination of product design has been the evolution of a strikingly large and complex standard-setting community charged with the responsibility and authority to negotiate and adopt standards for their industries. In addition, liaisons and affiliations among standard-setting bodies have been formed across industry and national boundaries as the need has arisen. The result is a standards community comprising hundreds of committees and involving over a hundred thousand individuals. It is particularly remarkable that, for the most part, this community has emerged at the initiative of industry participants and without governmental intervention or direction. Indeed, governmental agencies often take their guidance from the industry bodies and formally adopt as mandatory standards the voluntary standards that these bodies produce.

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[14]An alternative is the adoption of "compromise standards" that borrow aspects of the technologies that the different participants prefer in a way that leaves none with an advantage. One reason that this approach may be used is that arranging for side payments is often difficult.

a. Voluntary Standard-Setting

A typical scenario for voluntary standard-setting is as follows: At some stage, usually fairly early in the development of a new product, manufacturers and purchasers realize that economies can be reaped by standardizing some of the product's components or features. These agents then create a body to consider the question of standardization. Often, this body is a subcommittee of an existing trade association or standard-setting organization. The subcommittee employs a lengthy and formal procedure to find the "best" standard that the parties will accept.[15]

Typically the task is broken into components. Memoranda are circulated to all interested parties for comment and are then revised repeatedly before the final standards document is adopted. Even after adoption, the document may still be revised to ensure that the standard evolves with the requisites of the technology. As mentioned above, the question of enforcement is moot since the benefits from coordination guarantee compliance.

In the above discussion, what is meant by an "acceptable" standard and what it means for a standard to be "adopted" have been kept deliberately vague. With regard to the meaning of an "acceptable" standard, writers on the standardization process have stressed the importance of "the consensus principle". This has been defined variously by different authors. In general it connotes "the largest possible agreement...among all interests concerned with the use of

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[15]See Sullivan (1983) for more details about this process.

standards.." (Verman (1973), p. 12). It is explicitly not taken to imply unanimity (Sanders (1972)). Certainly it does not imply a simple unweighted majority of industry participants. As Hemenway (1975, p. 89.) notes, "A weighty objection of one important organization may outweigh all other affirmative votes. Or a number of negative votes of groups that are only distantly concerned with the subject matter may be discounted in the face of the affirmative votes of parties that are vitally affected by the standard".

"Adoption" follows the reaching of consensus. In principle, adoption could just mean distributing the standards document to those that have participated in its creation. In practice, however, it is useful to have a central clearinghouse that keeps track of, and disseminates information about, standards. This avoids duplication and ensures that interested parties who were not involved in the process can utilize the standard. In the U.S., this clearinghouse function is provided by the American National Standards Institute (ANSI). Created in 1918,[16] ANSI is a private organization with more than 220 trade associations, professional and technical societies, and more than 1000 corporations as members (NBS (1984)). ANSI approves a standard when it finds that its criteria for due process have been met and that a consensus among the interested parties exists. Some 8500 American National Standards have been approved in this manner (NBS (1984), p. 71).

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[16]Originally organized as the American Engineering Standards Committee, comprising four engineering societies, mining, civil, chemical, and mechanical, its name was changed to the American Standards Association in 1928. At that time, its membership was opened to trade associations and government bureaus. Finally, from 1966-69 it was reorganized under the name of ANSI and the focus of its role shifted from standards creation to a broader coordinating role. (See Sullivan (1983), p. 33 and Hemenway (1975), p. 88).

In the United States, the decisions of standard-setting bodies, and their operating procedures, have been subject to antitrust scrutiny. At least three organizations have been held to have violated the antitrust laws when they refused to certify that a new technology conformed to an industry standard.[17] As a result, the principle has been established that antitrust liability may be incurred by private voluntary standard-setting organizations if their actions are anticompetitive,[18] and these organizations must now expect that their activities may be subject to challenge. Indeed, in one situation of which we are aware, a trade association actually declined to adopt an industry standard because it feared that it could avoid antitrust liability only by adopting costly procedures to assure that its actions would be perceived as "fair."[19]

The need for standards transcends national boundaries. The same forces that produced the formation of national standards bodies have also led to the creation of organizations for international standardization. In 1946, delegates from 64 countries established the

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[17]See American Society of Mechanical Engineers, Inc., v. Hydrolevel Corporation, 456 U.S. 556 (1982), Radiant Burners, Inc. v. People's Gas Light & Coke Co., 364 U.S. 656 (1961), and Indian Head, Inc. v. Allied Tube & Conduit Corporation, United States Court of Appeals for the Second Circuit, 1987, slip opinion. See also Federal Trade Commission (1983) for an extended analysis of the potential for anticompetitive behavior in the development of standards.

[18]However, collective activity to influence *government* standard-setting is generally immune from liability under the antitrust laws. The Noerr-Pennington Doctrine adopted by the courts provides substantial antitrust immunity to firms acting collectively to influence legislative or regulatory behavior. See Fischel (1977) and Hurwitz (1985) for useful discussions of the Doctrine.

[19]See the discussion of the behavior of the National Association of Broadcasters in deciding whether to adopt an AM stereo standard in Besen and Johnson (1986).

[20]The ISO was preceded by the International Federation of the National Standards Association (ISA), formed in 1926 by about 20 of the world's leading national standards associations. The ISA disbanded in

International Standards Organization (ISO).[20] In 1947, the International Electrotechnical Commission (IEC), formed some 43 years earlier, became affiliated with the ISO as its electrical division, considerably expanding its scope. There are two striking features of the ISO: its extent and the rate of growth of its output. Of the roughly 7500 international standards that had been written by early 1985, some 5000 had been developed, promulgated, or coordinated by the ISO (Lohse (1985)). This contrasts with the mere 37 ISO Recommendations that had been approved by the ISO's tenth anniversary in 1957, and the 2000 standards that had been written by 1972 (Sanders (1972), p. 68).

As is the case with ANSI, the ISO is a nongovernmental, voluntary institution. It has 72 "full members" and 17 "correspondent members". The full members are national standards associations, such as ANSI, which have voting rights on the technical committees of the ISO as well as the Council and General Assembly.[21] The correspondent members are governmental institutions from countries that do not have national standards bodies. The writing of the standards is carried out by the 164 technical committees and their subcommittees and working groups of which there are about 2000 (Lohse (1985)). It is estimated that the number of individual participants has grown from some 50,000 in 1972 (Sanders (1972, p. 68.) to over 100,000 today (Lohse (1985), p. 20.). Some 400 international organizations, including the CCITT, which will be discussed below, have formal liaison with the ISO.

1942 because of the war. (Sanders (1972), p. 64.) In 1981 the ISO changed its name to "International Organization for Standardization" but retained the abbreviation ISO (Rutkowski (1985), p. 20).

[21]The ISO accepts as a member the national body that is "most representative of standardization in its country". Most of these (more than 70%) are governmental institutions or organizations incorporated by public law. (Rutkowski (1985), p.21).

The same process of developing, circulating, and revising drafts that characterizes national standard setting is present in the international arena.[22] Although the consensus principle is held as an ideal for the standards process at the international level as well (Sanders (1972), p.12), formally a Draft International Standard (DIS) must be approved by 75% of the full members who have elected to participate in the relevant technical committee. "Two or more negative votes receive special consideration" (Lohse (1985), p.22). Once a DIS has been approved by a technical committee it must be adopted by the Council of the ISO as an International Standard.

It is significant that the number of ANSI standards exceeds the number of international standards. Because international standardization is a relatively new phenomenon, standardization is often achieved at the national level before it is taken up internationally. Indeed, in its early years, the ISO was mainly involved with coordinating existing national standards.

b. Standard-Setting in the Telecommunications and Computer Industries

Due to the great economies of scale and scope in constructing and operating telephone networks, telephone services have traditionally been provided by Government-run (or, in the U.S., Government-regulated) monopolies. In Europe these are the PTTs (Post, Telephone and Telegraph Aministrations), while in the U.S., until recently, this position was held by AT&T. So long as these organizations had complete control over

[22]See Lohse (1985) and Sanders (1972) for more detail on the functioning of the ISO.

the design and use of the network, standardization within countries involved only a single firm. However, international standardization, requiring coordination among many firms, involved consultation and agreement among national Governments. It is not surprising, therefore, that there exists a treaty-based organization to deal with standardization issues.

The International Telegraphic Union was formed by an agreement of 20 countries in 1865. In 1932, it merged with the organization created by the International Radiotelegraph Convention and was renamed the International Telecommunication Union (ITU).[23] The main goal of the ITU, which currently has 162 members, is to promote cooperation and development in telecommunications. The branches of the ITU most concerned with issues of standardization are the International Telegraph and Telephone Consultative Committee (CCITT) and the International Radio Consultative Committee (CCIR). The latter is concerned with matters specifically related to radio propagation and facilities, while the former deals with all other telecommunications issues.

The results of CCITT and CCIR deliberations are usually adopted as *recommendations*. While these are not legally binding, countries find it in their interests to adhere to them in order to facilitate interworking of national systems. Although rarely done, the ITU can adopt CCIR and CCITT recommendations as treaty agreements (known as *regulations*). While these have been restricted mainly to issues relating to radio, importantly, the 1988 World Administrative Telegraph and Telephone Conference will consider regulations affecting "all existing and forseen new telecommunications services".[24]

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[23]See Bellchambers, Francis, Hummel and Nickelson (1984) for details of the history of the ITU.

[24] Resolution No. 10 of the Plenipotentiary Conference of the ITU (Nairobi, 1982), cited in Rutkowski (1985), p. 261.

Since the CCITT is a part of a a treaty organization, the U.S. is represented there by a delegation from the Department of State. Two public advisory committees, the United States Organization for the International Telegraph and Telecommunications Consultative Committee (USCCITT) and the United States Organization for the International Radio Consultative Committee (USCCIR), provide advice to the State Department on matters of policy and positions in preparation for meetings of the CCITT (Cerni (1985)).[25] The State Department is also able to provide accreditation to organizations and companies that allows them to participate directly in CCITT and CCIR activities. Historically U.S. representation has been made in this way through companies involved in the provision of telegraph and telcommunications services (Rutkowski (1985), p. 25).

Several domestic voluntary standards organizations are also involved in the telecommunications standardization process. One of the most important of these is Committee T1 sponsored by the Exchange Carriers Standards Association (ECSA) which was organized after the divestiture of the Bell Operating Companies from AT&T to deal with standardization issues previously handled internally by AT&T.[26] This committee, whose members include exchange carriers, interexchange carriers, and manufacturers, develops interface standards for U. S.

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[25]"Membership [in the USCCITT] is extended to all parties interested in telecommunications standards, including users, providers, manufacturers, national standards organizations, and Government Agencies". (Cerni (1985), p.38).

[26]See Rutkowski (1985) for details of ESCA and other voluntary standards organizations and Lifschus (1985) for a description of the activities of Committee T1.

networks. Although the private sector plays a large role in the development of U.S. telecommunications standards, it does so subject to the substantial authority of the Federal Communications Commission (FCC) to regulate domestic and international communications under the Communications Act of 1934.[27]

Standardization decisions lie at the core of the establishment of telecommunications networks.[28] The same is not true of computer hardware technology. Especially in the days when the mainframe reigned supreme, the major uses of computers were as stand-alone processors. Standardization issues revolved mainly around the ability of manufacturers of peripheral equipment to connect their products to the Central Processing Units of other manufacturers. Since there was a relatively small number of mainframe manufacturers, and since they provided integrated systems, and hence were not dependent upon the equipment of peripheral manufacturers, there was little incentive to ensure that interfaces were standardized.[29]

Several factors have combined to increase the desirability of inter-computer communication. These include: the desire to make corporate and external data available to a wide range of company employees; the need

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[27]Title I provides the FCC with general jurisdiction over communications services, Title II with specific jurisdiction over common carrier telecommunications services, and Title III with jurisdiction over the use of Radio Stations.

[28]This is not to say that they are essential, since often translators can substitute for interface standards. However, whether standards or translators are used, the issue of whether or how to standardize naturally arises.

[29]Users of computer languages, on the other hand, had obvious incentives to achieve standardization and utilized the typical voluntary committee structure.

to share information generated in a decentralized way resulting from the emergence and rapid acceptance of the microcomputer; and the increase in the use of computer technology in the service economy (e.g., banking, airline and theater reservations) and the desire to access these and other potential services (e.g. home education, library access, grocery ordering, household mail and mail answering etc.) from the home.

The first important successes in standardizing data communications were not achieved until the mid-1970's. One of the most important early standards was CCITT Recommendation X.25 which established interface specifications between data terminal equipment and public data networks.[30] These early standards were imperative for meeting immediate requirements - they were not components of a grand design that would ensure compatibility of different protocols and system architectures (Folts (1982)).

The initiative for developing an overarching framework for information transfer between any two end-systems was taken by the ISO. The ISO initiative is generally perceived as a bold and farsighted attempt to avoid a haphazard evolution of incompatible protocols. In contrast to many standards proceedings, this initiative anticipated future needs rather than merely reacting to them.

The result of this initiative was the Open Systems Interconnection (OSI) reference model. This model provides a framework for structuring communication between separate end-users. The term "open" conveys the

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[30]These protocols are essential for packet-switched networks. In such a network, data to be transmitted from one user to another are arranged in "packets". In addition to the data, each packet includes such information as the users' addresses. Protocols establish, *inter alia*, call origination and acceptance formats, error checking, speed and flow parameters. See Rybcynski (1980) for the details of X.25.

ability of any end-user to connect with any other. The forum in which such communication takes place is called the "OSI environment". An "end-user" is best thought of as a particular applications process (Folts (1982)). Thus, for example, an end-user could be a person operating a manual keyboard terminal, or a production-line control program.

The communication between application processes requires that a number of functions be performed. The OSI Reference Model structures these functions into seven layers.[31] Broadly speaking, the upper three layers provide support for the particular application being used. They provide the services that allow the application process to access the Open System and to interpret the information being transferred to the application process. The lower three layers are concerned with the transmission of the data itself from one applications process to another. The middle layer (the "transport" layer) links the application process support layers to the information transmission layers.

Contemporaneous with the blossoming of opportunities from inter-computer communication has been a major change in the technology of telecommunications networks. Voice communication requires both a transmission and a switching technology. The transmission technology carries the voice signal through the network, while the switching technology is responsible for its routing. The traditional analog technology amplifies the voice signal in such a way that it can be transmitted. Each time the signal is switched, the signal must be interpreted and then transformed again and this process results in the accumulation of "noise."

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[31]See Folts (1982) or Tannenbaum (1981) for a more detailed description of OSI.

The alternative digital technology immediately creates a digital representation of the voice signal. This digitized signal can then be switched repeatedly without decoding and redigitizing. Since the signals are in digital form, the switching is performed by computer. As the cost of computer technology has fallen, so has the cost of the digital technology. Accordingly, telecommunications networks are rapidly being transformed from analog to digital transmission and switching. Eventually, the entire telecommunications network will be digital, forming an Integrated Digital Network (IDN).

Once the telecommunications network transmits digital information, this network itself can be used for the kind of inter-computer communication discussed above. This vision of a single network that will be used for voice, data, facsimile, and video transmission is referred to as the Integrated Services Digital Network (ISDN). Because of the obvious connection between the work of the ISO on OSI and the interests of the CCITT in telecommunications, these two bodies are working together closely in developing standards for ISDN.[32]

4. NONCOOPERATIVE STANDARD-SETTING

An alternative to setting voluntary standards through committees is for standards to evolve through the adoption decisions of market participants. In order to evaluate the utility of the committee system, or the desirability of imposing mandatory standards, it is therefore necessary to understand how well "the market" would do in setting *de facto* standards.

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[32]Technical Committee 97, headquartered at ANSI in New York, is the ISO subcommittee responsible for ISDN standards (Rutkowski (1985), p. 17).

There are several dimensions along which the market's performance should be evaluated. These include whether the market selects the appropriate standard; whether inferior standards are abandoned when new, superior, technologies become available; whether the appropriate trade-off between variety and standardization is made; and whether converter technologies are appropriately developed. These important economic issues were virtually ignored by economists until quite recently. A burgeoning theoretical literature is attempting to correct this failing. This section briefly reviews this literature.

The distinctive feature of the models discussed here is that the benefits of standardization create a demand-side economy of scale. In particular, where there are benefits to compatibility, users of a particular technology reap benefits when others adopt the same technology. Thus one individual's adoption decision confers a positive externality on other adopters. Since individual decision-makers ignore these externalities in making their decisions, one cannot generally expect the outcomes to be efficient. Indeed, as we shall see, inefficiencies of various kinds can arise.[33]

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[33]Two other issues about the effect of standardization on market structure and firm behavior are also important. The first is whether, in the presence of benefits from compatibility, firms can take strategic actions to disadvantage their rivals. When an individual firm has the ownership rights to a given technology (such a firm is often called a "sponsor" of the technology in this literature), the adoption of the technology as a standard will confer some monopoly power. Thus each firm may be expected to take measures to encourage the adoption of its technology as the standard, and to protect and extend its monopoly power once it has been achieved.

The second issue is of particular importance in markets, such as telecommunications, where customers use a primary product (the telephone network) in conjunction with secondary services (e.g., customer premises equipment and enhanced telecommunications services). In such markets the question arises whether firms with a dominant position in the

a. Inertia and Momentum in the Adoption of a New Standard

The benefits from standardization may make users of a standardized technology reluctant to switch to a new, and perhaps better, technology, out of fear that others. bound together by the benefits of compatibility, will not abandon the old standard. If this is the case, it may be difficult for a new standard to be adopted. As a result, *de facto* standardization may retard innovation.

The first theoretical model of this phenomenon is due to Rohlfs (1974) who considers what happens when a given number of agents are simultaneously considering adopting a new technology.[34] Suppose that all potential adopters would adopt if each knew that the others would do so as well. However, no individual would adopt if he thought that he would be the only adopter. Rohlfs points out that there are generally multiple equilibria in this situation. One is for everyone to adopt the new technology while another is for no one to adopt it. Similarly, if some subsets of users are in favor of adoption but others are not, still other equilibria are possible.

Consider four potential adopters, which we can number 1,2 3,and 4. Suppose that 1 and 2 will adopt if the other does but that 3 and 4 will adopt only if the other does and 1 and 2 also adopt. Even if all four agents are better off adopting, it is conceivable that inertia will lead to an equilibrium in which only 1 and 2 adopt, if that outcome is somehow "focal".[35]

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primary market can employ control of interface standards to profitably extend their dominance to the secondary market. These two issues are discussed in Section 5.

[34]The Rohlfs model is actually cast in terms of agents choosing whether or not to join a telecommunications network, but the analogy to the choice of a standard is complete.

[35]How 1 and 2 manage to coordinate their behavior is, of course,

A second problem is that it may not be an equilibrium for all four to adopt and yet that may be the most socially desirable outcome. This occurs, for example, when 3 and 4 are moderately reluctant to adopt the technology but their adoption would make 1 and 2 much better off. Since 3 and 4 ignore the benefits that they confer on 1 and 2 in making their adoption decision, too little adoption may occur.[36] Indeed, 1 and 2 may not adopt the new technology if they are unsure that 3 and 4 will do so.[37]

Farrell and Saloner (1985) demonstrate that some of these potential inertia problems disappear if we allow for sequential rather than simultaneous decision-making and complete information. In that setting, they show that where all agents prefer joint adoption of the new technology to the *status quo*, adoption is the unique equilibrium.[38] Moreover, if the agents do not all prefer joint adoption of the new technology, the only equilibrium involves the largest set of possible

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important. The point of the example, however, is that 3 and 4 may be unsuccessful in achieving coordination even if 1 and 2 can do so. Note that this is an example of Pure Coordination if all four agents are better off adopting. If this is the case, a standard-setting body would succeed in promoting adoption of the new technology.

[36]Dybvig and Spatt (1983) demonstrate that in some cases relatively simple subsidy schemes may alleviate both of these problems.

[37]Note that this is an example of Conflict and cannot be resolved by replacing non-cooperative standard-setting with a standard-setting body. Agents 3 and 4 will not switch even if 1 and 2 agree to do so.

[38]The proof uses the following backwards induction argument. Suppose that there are N potential adopters and N-1 have already adopted the technology. In that case, the Nth adopter will as well. Therefore consider the N-1th adopter when N-2 have already adopted. That potential adopter knows that if he adopts that the final adopter will also, and so he, too, adopts. The same logic can be applied all the way back to the first adopter. This explains why a standard-setting body can succeed in achieving universal adoption only in the first of the two examples discussed above.

adopters. Of those that do not adopt, there is no subset that desires to switch. This result suggests that the intuition about the possible innovation-retarding effects of standardization does not extend to a model where the timing of the adoption decision is endogenous and information is complete.

However, while this model provides a useful benchmark, it suffers from a lack of realism along a number of dimensions. First, the assumption that all potential adopters are perfectly informed about each others' preferences is not innocuous. Second, the model has a timeless quality to it. There are no transient costs of incompatibility, nor is adoption time-consuming. Finally, all potential adopters of the technology are extant at the time the adoption is first contemplated. In reality, some potential adopters will make their decision only some time in the distant future.

Richer models have been developed to incorporate each of these features. The conclusion that emerges uniformly from these studies is that the outcome of the adoption process may be inefficient. However, the inefficiency is not only that a socially efficient standard may not be adopted. It is also possible that a new standard may be adopted too readily, i.e., it may be adopted when, from a social point of view, it should not be.

For example, Farrell and Saloner (1985) consider what happens when two potential adopters are imperfectly informed about each other's preferences. They find that the outcome resembles a "bandwagon": if one potential adopter is very keen on the adoption of the new technology it will adopt early in the hope of inducing the other to follow. If a potential adopter is only moderately keen, it will employ a "wait-and-see" strategy, adopting only if the other is more eager and gets the bandwagon rolling.

"Wait-and-see" behavior can have the effect of stalling the bandwagon even when both potential adopters hope that adoption will occur. Thus, there may be too little standardization.[39] However, the converse is also possible. Suppose that two firms are currently both using an existing technology when a new technology becomes available and that only one firm favors switching to the new technology. That firm may adopt the new technology leaving the other with the choice of being the lone user of the old technology or switching as well. If the benefits to compatibility are large, the latter may find switching to be its best alternative. However, the firm that opposes the switch may be hurt more than the firm that favors the switch benefits, so that firms in the aggregate are worse off than if they had remained with the old technology.[40]

Not only has it been shown that incomplete information can lead either to "excess inertia" or "excess momentum" in the adoption of a new technology, but Farrell and Saloner (1986b) provide two models in which this can occur even with complete information. The first model examines the case where only new adopters consider a new technology but the installed base of users of an old technology does not find switching profitable. Excess inertia can arise here if the first potential

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[39]Postrel (n.d.) has extended the Farrell and Saloner (1986) results to the N-agent case.

[40]Thus, although "bandwagons" may overcome the need to employ cooperative standard setting to achieve efficient adoptions, they may also promote inefficient ones. Moreover, in the latter case, cooperative standard-setting may not only fail to overcome this tendency but it may actually promote it.

adopters to consider the new technology are not prepared to give up the transient benefits from being compatible with the installed base of the old technology. They then adopt the old technology, swelling the ranks of the installed base and making the old technology even more attractive. In that case the new technology cannot get off the ground. This can happen even if the new technology would be much preferred by most new users if it became established. The failure of the market in this case is that the first potential users to consider the new technology confer a benefit on later adopters that they do not take into account in making their adoption decisions. Cooperative standard-setting will not be able to overcome this problem because, by assumption, early potential adopters value highly the benefits of compatibility with the installed base.

However, excess momentum can also occur. This happens when the new technology is adopted, but the harm imposed on users of the old technology, who are thereby stranded, exceeds the benefit to new adopters from the new technology. This result is important because it suggests that simple public policies aimed at encouraging the adoption of new technologies can exacerbate an existing bias in the market.[41]

The second model examines what happens when adoption takes time. Here, all potential adopters of a new technology are users of an old one. The first adopter of the new technology will lose any

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[41]Rosenberg (1976) and Stoneman and Ireland (1984) also show that such policies can have the unexpected effect of slowing the adoption of new technology. An adopter of a new technology knows that these policies provide an incentive to new innovation, increasing the chance that the new technology will itself soon be obsolete. See David (1986c) and David and Stoneman (1985) for a discussion of these and other implications of public policy aimed at hastening technology adoption.

compatibility benefits he currently enjoys until others also adopt the new technology. At the same time, any user who does not switch to the new technology may find himself temporarily stranded with the old technology if other users switch before he does. If the first of these effects is very strong, excess inertia may arise with no potential adopter willing "to take the plunge," with the result that all remain with the old technology. If the latter effect is very strong, excess momentum may arise, with each potential adopter rushing to be the first to adopt out of fear of being temporarily stranded.

In the above models, potential adopters choose between the *status quo* and a single new technology. Arthur (1986) shows that the "wrong" technology may be chosen even when a sequence of first-time potential adopters are choosing between two new technologies.[42] As in the Farrell and Saloner (1986b) model discussed above, early adopters are pivotal. If most favor one of the technologies and adopt it, it becomes relatively less expensive for later adopters who, in turn, may find it uneconomical to adopt the other technology. However, if the majority of later adopters would have preferred the other technology, society may have been better served by its adoption. In that case, the chance predisposition of early adopters to the socially inferior technology, and the fact that they serve their own, rather than society's, interests, results in the the less preferred technology being chosen as the standard.[43]

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[42]In the simplest version of Arthur's model, the demand side externalities arise from "learning by using," where each time a potential adopter selects one of the technologies, the costs to later users of the same technology are reduced. However, the model can easily be extended to the case of compatibility. See David (1986a) for a discussion of this point.

[43]Cowan (1986) analyzes the same phenomenon from a different perspective. As in Arthur's model there is learning by using. In

b. Communication, Cooperation, and Contracts

In many of the cases in which an inefficient standard emerges, the failure of the market to select the "right" standard could be avoided if all potential adopters could somehow coordinate their activity and make appropriate side payments. For example, where it is inefficient for a new standard to be adopted because of the harm inflicted on the installed base, the installed base of users would be willing to subsidize new adopters to adopt the old technology. If such contracts and side payments could overcome any inefficiencies, it is important to know why they will not naturally arise within a market setting.

Several possible reasons exist. The most important of these is that many of the agents whose adoption decisions are relevant are not active market participants at the time the new technology becomes available, but arrive much later. In principle, one could imagine a scheme in which a fund is provided by current users to provide subsidies to later adopters as they arrive. However, each current member of the installed base would have an incentive to free ride on the contributions of the others, or if a method of taxes and subsidies was used, to understate their true aversion to stranding.[44] Moreover, if, as in Arthur's model, there is uncertainty about the preferences of future

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addition, however, potential adopters are unsure which technology is better. Each trial of a technology provides some information about its desirability. Thus, as in the above models, there is a connection between the welfare of late adopters and the decisions of early ones. Since early adopters ignore the value of the information they provide to late ones, from a social point of view there may be too little exploration of the value of alternative technologies.

[44]This free rider problem would arise, of course, even if the model were "timeless".

adopters, even a central authority would often err in its choice of a standard.[45]

An additional difficulty arises if there is asymmetric information about adopters' preferences. Farrell and Saloner (1985) explore the implications of communication in their asymmetric information bandwagon model and find that communication is a mixed blessing. Where potential adopters are unanimous in their desire to adopt the new technology, communication facilitates coordination and eliminates excess inertia. However, if they have differing preferences, communication can actually make matters worse. A potential adopter who is only slightly averse to the adoption of the new technology will exaggerate his degree of aversion, making it even less likely that a bandwagon will get started. This suggests that there are circumstances in which inertia may actually be *increased* if there is an attempt to set voluntary standards through industry committees.[46]

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[45]David (1986b) calls such a central authority a "blind giant."

[46]Another portion of the literature addresses the trade-off between standardization and variety. Farrell and Saloner (1986) show that when the degree of standardization is left to market forces, too little variety may be provided if the existence of an historically favored technology prevents an otherwise viable alternative from getting off the ground. Matutes and Regibeau (1986) address the case in which products are combined in "systems" and show that standardizing the product interface can *increase* the variety of systems by facilitating "mix-and-match" purchases. However, it can also lead to higher prices.

The compatibility of *components* may also have implications for technology adoption. Berg (1985) compares a regime in which there are two competing technologies with one in which there is only one technology. In the former, there is the possibility that one of the technologies will become the *de facto* standard as time progresses. In that case, the adopters of the abandoned technology may find that compatible components are no longer provided. The realization of this possibility will tend to dampen the demand for both technologies, leading to slower technology adoption. Farrell and Gallini (1986) show that a monopolistic supplier of the primary good may encourage competition in the component market in order to mitigate this problem.

c. The Development of Translator Devices or "Gateway" Technologies

In the above analyses, potential adopters face the choice between two inherently and unalterably incompatible technologies. In practice, however technical compatibility is not required for two components of a system to be able to "communicate." Where components have not been designed to be compatible, devices, variously known as translators, adapters, converters, or gateways, can often be employed to permit them to interact.[47] Indeed, if translation were costless and technically perfect, standardization would be unnecessary.[48] However, translation is often costly and something is often "lost" in translation. Nonetheless, there is a thriving business in the sale of devices that permit communication in the absence of compatiblity.[49]

The existence of translators has a number of implications for standardization, most of which have not been addressed in the theoretical literature:

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[47]See Braunstein and White (1985) for a brief discussion of translators as a substitute for standards.

[48]By technically perfect we mean that messages sent in either direction and then returned are identical to those that were orginally transmitted.

[49]Some examples of translation devices presently being marketed to permit communication are: (1) Word For Word which is a "software document converter that converts files and documents from one PC-compatible word processing system to another." (Advertisement in *Byte*, 1986 Extra Edition, p. 229); (2) A series of products offered by Flagstaff Engineering that "can connect your incompatible computer systems using diskette, tape, communications, or printed media....," (Advertisement in *Byte*, September 1986, p. 320); and (3) PC<>488 which "allows your IBM PC/XT/AT or compatible to control IEEE-488 instruments...." (Advertisement in *Byte*, November 1986, p. 155).

First, in some circumstances, the use of translators may be more efficient than the development of standards. Standard-setting is costly, and if only a small number of users wishes to combine incompatible components it may be less costly for them to employ translators than to attempt to achieve standardization. Moreover, if the principal uses of the incompatible components are to serve users with different needs, important benefits may be lost if standardization is required.

Second, translators are likely to be important during the period in which a number of incompatible technologies are vying to become the industry standard and consumers wish to have access to a larger "network" than any single technology can provide. The existence of translators permits the deferral of the choice of a standard until more information about the respective technologies becomes available. This does not mean, of course, that either the market or standard-setting bodies will necessarily select the efficient standard after the period of experimentation, but better choices may be possible if there are more data about the competing technologies.

Third, the existence of translators may promote the development of specialized uses for particular technologies and thus narrow the range of uses of each. David and Bunn (1986) argue, for example, that the development of the rotary converter for "translating" AC to DC electrical current delayed the development of high voltage DC transmission.

Finally, the presence of translators may reduce the incentives to achieve standardization. So long as incompatible components can be combined into a system, consumers are likely to be less willing to demand that manufacturers standardize and manufacturers are likely to be less willing to incur the costs of doing so.

Nonetheless, it is possible to overstate the extent to which translators can and will substitute for standards. There are likely to be cases in which translation is technically inefficient and/or in which the costs of achieving translation are high.[50] A number of large communications users have emphasized to us the value to them of having standardized communications networks and have argued strongly that, for them, translators are a poor substitute. They are thus likely to be an important force in promoting standardization.

5. STANDARDS AND COMPETITION

For the most part, the models discussed in the previous section have in common that the prices for the different technologies that the potential adopters face are not explicitly considered. This is consistent with markets in which the various technologies are competitively supplied so that adopters face competitive prices. This feature of the models is important since if, instead, the technologies were offered by firms with some market power, the firms might have an incentive to behave strategically. In this section we focus on strategic actions of three kinds: First, we analyze the effect of

[50]Also, Katz and Shapiro (1985) have shown that firms providing incompatible technologies will generally not have the correct incentives to provide converters.

strategic pricing on the market's choice of technology. Second, we examine the effect of truthful advance announcements by firms that they propose to introduce a new product. Finally, we study the contention that leading or dominant firms, or firms with control over "bottleneck facilities," might use their positions to choose or change standards in order to disadvantage their rivals.[51]

a. Strategic Pricing and Product Preannouncements

Katz and Shapiro (1986a) examine the implications of strategic pricing in a two period model when there is competition between two technologies. The most interesting case they consider is one in which each technology is offered by a single firm and one technology has lower costs in the second period, but higher costs in the first period.[52] They find that the sponsor of the technology that will be cheaper in the future has a strategic advantage. This is a somewhat surprising result and its flavor is exactly the reverse of that in the models of the previous section, where there is a tendency for adopters to choose the technology that is more attractive at the time that they adopt.

The intuition behind their result is the following: Where each technology is provided by a single sponsor, that firm has an incentive to price very low early on, even below its cost, to achieve a large installed base and become the industry standard. However, potential adopters know that later on ("in the second period") the firm will no longer have an incentive to use "promotional" pricing and will charge a

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[51]See Adams and Brock (1982) for an example of this view.

[52]They also study the case where both technologies are competitively supplied. Their results in that case are similar to those of Farrell and Saloner (1986b) discussed in the previous section.

higher price. Potential adopters therefore expect the firm that will have the lower future costs also to have the lower future prices. If both firms charge the same first period price, potential adopters will therefore prefer the technology that will have lower future costs. Put differently, the firm that has higher first period costs can overcome that disadvantage by promotional pricing. However, the firm that has higher second period costs cannot do the same since consumers will rationally expect the firm to exploit its dominant position at that stage.

Strategic behavior results in lower prices for consumers. It does not, however, guarantee that the technology with the lower overall cost is adopted. At the same time, however, a ban on promotional pricing might prevent the adoption of the technology with the lower cost.

Similar problems arise in the the model developed by Farrell and Saloner (1986b). Recall that in that model there is an installed base of users of an old technology when a new technology becomes available. As a polar case, they consider what happens when the new technology is supplied by a competitive industry, while the old technology is supplied by a monopolist. They show that in some circumstances the monopolist will be able to prevent the new technology from being adopted by offering a discount to potential adopters.[53] Importantly, this discount need not be offered to all adopters. Instead, there may be some critical installed base at which the old technology will become invulnerable because the compatibility benefits from joining the

[53]The same advantage exists when a monopolist is the supplier of a new technology that is incompatible with one offered by a competitive industry.

installed base are so large. Once that point is reached, the monopolist need no longer offer a special inducement. There is thus a window of opportunity for the new technology which the monopolist may be able to close through strategic pricing. Moreover, this entry prevention tactic may be successful even where the new technology would have been superior from a social point of view.[54]

The Farrell and Saloner (1986b) model can also be used to demonstrate that a simple announcement that a product will be available in the future (a "product preannouncement") can make the difference between the adoption and nonadoption of a technology. To see this, suppose that the *old* technology is competitively supplied, but that the new technology is supplied by a monopolist. By the time the monopolist is ready to introduce its product the installed base on the old technology may make entry impossible. By preannouncing the introduction of a new product, the monopolist may be able to induce some potential adopters to wait for its arrival. If that occurs, the new product will begin with an installed base of its own, making it the more attractive technology to later adopters. As in the case of strategic pricing, the preannouncement can result in the adoption of the socially less-preferred technology, in this case because it leads to the stranding of users of the old technology.

b. Standards and "Bottleneck" Facilities

For the most part, the theory of non-cooperative standard-setting discussed thus far focuses on the market for a "primary" good, e.g., computers, in which compatibility is sought, or avoided, because of its

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[54]Katz and Shapiro (1986b) find the same result in their two-period model.

effect on demand in the primary market. In those analyses, the effect of the firms compatibility, pricing, and preannouncement decisions in the primary market on the market for the secondary good is not analyzed in detail, because it is implicitly assumed that producers of the primary good do not participate in that market.

The situation in the telecommunications market is somewhat different. Here, one set of firms, the local telephone companies, is assumed to control the market for basic telephone transmission capacity, the primary market.[55] At the same time, these firms are, or would like to be, participants in the secondary markets for customer premises equipment (CPE) and enhanced telecommunications services. The questions that face regulators are (i) whether control of the primary market can be extended, through the use of standards or in other ways, to the secondary markets and (ii) whether the local telephone companies will have the incentive to attempt to "leverage" their market power in this manner.[56]

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[55]Whether this presumption is true is not addressed in this paper, although the conclusions would be affected if there were effective competition in the transmission market. Similar issues arise in countries where a single entity controls the entire telecommunications system and competes with outside suppliers. This explains the large role given to the achievement of common standards by the Commission of the European Communities (1987). Thus, the Commission is concerned with "the promotion of Europe-wide open standards, in order to give equal opportunity to all market participants." (p. 5).

[56]This is akin to the issues raised in the various antitrust cases involving IBM, where it was alleged, among other things, that IBM manipulated its interconnection standards to extend its putative monopoly in the market for mainframe computers to the market for peripheral equipment. This paper is not the occasion to revisit the issues raised in these cases. We raise the examples of the IBM cases only because they present analogies to policy questions in the telephone industry. For a vigorous defense of IBM's actions see Fisher, McGowan, and Greenwood (1983).

The use of standards to increase profits in either the "system" market or in the market for a complementary good is analyzed in detail in Ordover and Willig (1981).[57] They consider a firm that is either the only supplier of one component of the system, the "primary" component, or that has a cost advantage in producing that component.[58] Other components of the system can be produced by rivals at the same cost.[59]

It is well known that, if the firm has a monopoly over one component, it will often be able to obtain maximum profit without regard to the presence of rivals in the competitive market *so long as there are no constraints on the price, or prices, that it can charge.* Consider the simplest case in which all consumers place the same value on a system and all firms have the same costs in producing all components but

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[57]See also Ordover, Sykes, and Willig (1985). Ordover and Willig actually describe a number of ways in which firms might attempt to exercise such leverage. These include refusing to sell the primary good to a rival; selling only complete systems and not their components; selling both systems and 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. Thus, standards are only one of a number of tools that a firm can use strategically to disadvantage its rivals and to increase its profits. It should also be observed that these are all variants of the "raising rivals' costs" strategies analyzed in detail in Krattenmaker and Salop (1986).

[58]It should be clear that the component is called primary not because it is any more necessary than any other component but because of the advantage that the firm has in producing it.

[59]The ability to use standards in such an anticompetitive manner is severely limited if efficient low-cost translators are available. For example, a firm that seeks a competitive advantage by designing interfaces that cannot directly accomodate the products of its rivals will find the strategy unsuccessful if users can easily connect incompatible devices through the use of translators. In such circumstances, the firm is less likely to employ the strategy.

the "primary" one. Suppose that the cost of producing the primary component is 10, the cost of producing a secondary component by any firm is 5, and the value that each consumer places on a system, or its constituent components, is 25. If there are no constraints on the prices that the firm can charge, it can set the price of a system at 25, the price of the primary component at 20=[25-5], and the price of the secondary component at 5. The firm obtains a profit of 10=[25-10-5] on each system that it sells directly to consumers. However, even where a consumer purchases only the primary component from the firm, it still obtains a profit of 10=[20-10]. The firm is, thus, indifferent as to whether consumers purchase the entire system or only the primary component from it since its profits are the same in either case. If rival firms can produce the secondary component more efficiently, say at a cost of 4, the profits of the firm are actually increased if it leaves the market for the secondary component to them. It can charge a price of 21=[25-4] for the primary component and obtain a profit of 11=[21-10], which is larger than the profit of 10 it obtains from selling an entire system.

However, it may pay to eliminate a rival if there are limits on the prices that can be charged for the primary component. Thus, in the previous example, if the firm can charge at most 12 for the primary component, say, because of regulation, then so long as it can charge any price above its cost on the secondary component it will wish to eliminate its rivals and dominate the secondary market, as well. If it can, for example, charge 6 for the secondary component, its profits are 3=[12+6-10-5] if it can sell both components, or an entire system, while it can earn only 2=[12-10] if it is limited to selling only the primary component. Indeed, if the firm can charge 13 or more for the secondary component it can earn the entire monopoly profit even with the restriction on the price it can charge for the primary component. If, however, there are rivals in the provision of the secondary component, and if the firm must make the primary component available at a price of 12, its profits are limited to 2=[12+5-10-5]. This occurs because consumers will buy the secondary component from the firm's rivals if it attempts to charge a price in excess of 5. This is what gives the firm an incentive to eliminate its rivals. One way in which it can do so is to make its primary component incompatible with the secondary component manufactured by its rivals.

The firm might also wish to eliminate its rivals if different consumers place different values on systems and these differences are proportional to their use of the secondary component. Suppose, for example, that there are two consumers, one that places a value of 25 on a system consisting of one of each component and the other that places a value of 40 on a system consisting of one primary component and two secondary components. The firm's costs are the same as in the previous example.

If there is no competition in the secondary market, the firm can offer the primary component at a price of 10 and each of the secondary components at a price of 15, and capture the entire consumers' surplus. Its profits in this case are 45=[40+25-10-10]. However, if there are rival suppliers of the secondary component who can produce at a cost of 5, so that the firm must obtain its profits entirely on the primary component, it will sell the primary components for 20 and earn profits of only 20=[20+20-10-10].[60] Eliminating a rival is desirable because

[60]The firm's profits are the same if it sells only one primary

complete systems at discriminatory prices.

it permits price discrimination that would not otherwise be possible.[61] Once again, a possible strategy for eliminating rivals is to design the primary component so that it is incompatible with the components produced by rivals.

The two elements necessary for the types of strategies analyzed by Ordover and Willig to be employed both appear to be present in the telephone industry. First, there are regulatory constraints on the prices that can be charged for the primary product, access to the transmission network. These constraints take the form of limits both on the overall rate of return that the firm can earn and on the prices of individual services. Second, the primary product may be a "bottleneck" or "essential facility" that is needed if the suppliers of enhanced services or CPE are to be able to sell their wares.[62]

At the same time, one of the assumptions in the examples presented by Ordover and Willig must be brought into question. In their examples, the firm that controls the primary market does not, as a result, have a cost advantage in producing the secondary goods. In such cases, no loss in efficiency results from a ban on the participation of suppliers of the primary good in the secondary markets. Similarly, there is no loss from requiring them to participate in these markets through separate subsidiaries, so that instances of anticompetitive behavior can be more easily detected.

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[61]This is analogous to the argument that firms will vertically integrate forward in order to permit them to practice price discrimination. See Gould (1977).

[62]To the extent that suppliers of enhanced services or CPE can "bypass" the local transmission facilities of a telephone company, the ability of the telephone company to use standards anticompetitively is reduced.

In addressing the effects of the limitations placed on AT&T by its Computer II decision, however, the FCC noted that "the inability to realize...scope economies was one cost of structural separation for AT&T's provision of CPE; and we believe the elimination of such costs could well result in efficiencies for AT&T's provision of enhanced services, to the extent that such services could be integrated into or colocated with AT&T's basic network facilities."[63] And, in examining the effects of similar restraints on the BOCs, the Commission observed "that structural separation imposes direct costs on the BOCs from the duplication of facilities and personnel, the limitations on joint marketing, and the inabilty to take advantage of scope economies similar to those we noted for AT&T."[64] If the economies of scope noted by the FCC are important, a blanket ban on BOC participation in the CPE and enhanced services markets, although it might prevent anticompetitive behavior, might also prevent efficient supply.[65]

We conclude that the conditions are present under which standards might be used to disadvantage the competitors of those who control access to the telecommunications transmission system. To prevent these

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[63]Federal Communications Commission, Report and Order In the Matter of Amendment of Sections 64.702 of the Commission's Rules and Regulations (Third Computer Inquiry); and Policy and Rules Concerning Rates for Competitive Common Carrier Services and Facilities Authorizations Thereof; and Communications Protocols under Section 64.702 of the Commission's Rules and Regulations, CC Docket No. 85-229, Adopted May 15, 1986, released June 16, 1986, para. 80.

[64]Id., para. 90.

[65]See Phillips (1986) for a forceful statement of the proposition that substantial efficiency losses will result if the BOCs are confined to providing basic service.

and other forms of anticompetitive behavior, the FCC and the courts have either prohibited the telephone companies from providing certain services or have required that these services be provided through fully separated subsidiaries. However, if telephone companies have lower costs than these competitors, either a blanket prohibition or a separate subsidiary requirement might be unwarranted. As a result, the FCC has begun to pursue an alternative approach under which the restrictions on the telephone companies are eliminated and, at the same time, a regulatory framework to make the anticompetitive use of standards more difficult is established.

6. TELECOMMUNICATIONS STANDARDS, TELEPHONE REGULATION, AND THE FCC

Until the 1960s, AT&T manufactured and provided to its customers virtually all of their telephone equipment and its tariffs forbade customers from attaching equipment obtained from other suppliers to the AT&T system.[66] During this period, standardization was not a major national policy issue since there were no competing providers of equipment, or of communications services, who might be adversely affected by the standards that were chosen.[67] Moreover, given the disparity in size between AT&T and other telephone companies, the latter had little alternative but to follow AT&T's lead. Rutkowski (1985, p. 79) notes that "AT&T simply made network policy decisions within their (sic) corporate domain, occasionally dealing with the government on

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[66]Only in areas served by other telephone companies, e.g., General Telephone & Electronics, was equipment available from non-AT&T sources, but in those areas subscribers could obtain equipment only from their local telephone monopoly.

[67]Of course, consumer welfare could depend on the choices that were made.

national security matters, a few small carriers, and foreign administrations."

In 1956, however, the web of restrictions preventing the use of non-AT&T equipment began to unravel when a Federal Appeals Court ruled in the Hush-A-Phone case that an AT&T tariff that prohibited the use of "foreign attachments" was "an unwarranted interference with the telephone subscriber's right reasonably to use his telephone in ways which are privately beneficial without being publicly detrimental."[68] More far-reaching was the subsequent decision by the FCC in the Carterfone case.[69] The Carterfone was a device that permitted the operator of a mobile radio system to connect its subscribers directly to the public telephone system. AT&T attempted to prevent the use of the Carterfone, arguing that it threatened the integrity of the entire system. However, basing its decision in part on *Hush-A-Phone*, the FCC ruled that "a customer desiring to use an interconnecting device to improve the utility to him of both the telephone system and a private radio system should be able to do so, so long as the interconnection does not adversely affect the telephone company's operations or the telephone system's utility for others."

AT&T attempted to limit the impact of *Carterfone* by requiring a telephone company-supplied interface device to be used between a

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[68]In Hush-A-Phone Corp. v. U.S., 238 F.2d 266 (1956), the Court of Appeals for the D.C. Circuit overturned an FCC ruling that had upheld the right of the telephone companies to prohibit customers from using a passive device that could be attached to a telephone handset to prevent conversations of nearby persons from being transmitted to receivers at the other end.

[69]*Use of the Carterfone Device*, 13 FCC 2d 420; reconsideration denied 14 FCC 2d 571.

foreign, i.e. non-AT&T, attachment and the telephone system. This requirement was eventually overturned by the FCC and replaced by an equipment registration program.[70] Under the program, an independent manufacturer may ask the Commission to certify that use of a particular piece of equipment does not pose a threat to the physical integrity of the telephone system. Equipment that receives "type acceptance," i.e., FCC certification, can be marketed freely.[71]

In announcing its equipment registration program, the Commission required, with one minor exception, that "all terminal equipment be connected to the telephone network through standard plugs and jacks."[72] Rather than establishing standards, however, the Commission indicated its "belief that acceptable designs will be voluntarily arrived at by cooperative action between the carriers and the terminal equipment industry."[73] The approach of the FCC of leaving decisions about standards to industry participants continues to this day.

Although the *Carterfone* decision removed a *legal* barrier to the entry of independent suppliers, and the equipment registration program removed a *technical* one, there was still concern that AT&T could use its

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[70]56 FCC 2d 593 (1975). The Commission concluded, on the basis of ten years of experience, that the use of independently provided equipment did not result in a technical threat to the system.

[71]A somewhat different arrangement is in place in the United Kingdom. The British Standards Institution (BSI) is responsible for establishing standards for attachment of equipment to the British Telecom system and the British Approval Board for Telecommunications (BABT) determines whether equipment meets these standards. Both bodies are independent of the government and of British Telecom. For details see Solomon (1986).

[72]Id. at 611.

[73]Id.

monopoly power to disadvantage its rivals. To deal with this concern, in its Computer II decision[74] the FCC ruled that if AT&T and, initially, GTE, wished to offer terminal equipment and "enhanced" services--essentially all communications services other than the provision of "basic" transmission--they would have to be offered through separate subsidiaries. The principal rationale for the separate subsidiary requirement was to prevent AT&T from using its monopoly in transmission to cross-subsidize its activities in the putatively competitive enhanced services and terminal equipment markets. Indeed, the Commission argued that the separate subsidiary requirement, combined with the structure of the equipment market, made rate regulation of terminal equipment unnecessary.

The FCC also required that technical information that independent suppliers might need to compete in the provision of enhanced services and equipment had to be provided to them on the same terms as to the separate subsidiaries. In this regard, the Commission singled out "information relating to network design and technical standards, including interface specifications [and] information affecting changes which are being contemplated to the telecommunications network that would affect either intercarrier connection or the manner in which CPE is connected to the interstate network..." The FCC concluded that "...when it is disclosed to an enhanced services of (sic) CPE separate subsidiary, such information must be disclosed to the competitors of the subsidiary at the same time and under the same terms and conditions." (Para. 246) Although the requirement that competitors be provided

[74]FCC, *Second Computer Inquiry*, 77 FCC 2d 384 (1980).

information equivalent to that provided to subsidiaries limited the ability of AT&T to use standards to disadvantage its rivals, it was still possible that AT&T subsidiaries would prefer different standards from their rivals.

The decisions by the FCC to require standardized interconnection for terminal equipment and that technical information be provided to independent suppliers were -- together with the separate subsidiary requirement and the equipment registration program -- part of an effort designed to make it possible for independent equipment vendors to compete effectively in the supply of this equipment. Although the Commission did not itself participate in the process of establishing interconnection standards, leaving their determination to the industry, its policy has been enormously successful, at least as judged by the wide variety of equipment that is now available and by the sharp declines in the market shares of the telephone companies. In the early 1980's, AT&T's share of the Customer Premises Equipment market had declined to somewhat over 60 percent (U.S. House of Representatives (1981)) and by 1986 its share of Total Lines Shipped had fallen further to about 36 percent for handsets, 25 percent for key systems, and 20 percent for PBXs (Huber (1987)).[75]

The next stage in opening the market to independent suppliers was the settlement of the antitrust suit against AT&T and the operating companies.[76] The settlement separated AT&T Long Lines, the long

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[75]According to Solomon (1986), in the United Kingdom where entry of independent suppliers of terminal equipment did not begin until much later than in the U.S., non-British Telecom suppliers have captured half of the addition of the installed base of telephones since 1980 and about 10 percent of the key system market.

[76]United States v. Western Elec. Co. (American Tel. and Tel. Co.), 552 F. Supp 131 (D.D.C. 1982).

distance service, Western Electric, the manufacturing arm, and the Bell Laboratories, the research facility, from the telephone operating companies, the providers of local service. Not only were the operating companies placed into seven separate regional holding companies, but they were prohibited by the Modified Final Judgment from engaging in the manufacture of telephone equipment and were required to market equipment through subsidiaries that were legally separate from those that provided local telephone service. The rationale for these, and other, restrictions was that they would prevent the local Bell Operating Companies, the BOCs, from using their control over "bottleneck" facilities to compete unfairly in the equipment market and cross-subsidize their equipment sales from the profits of their local telephone monopoly. Although efforts are underway to relax or eliminate the "line of business" restrictions on the operating companies, their retention is strongly supported by independent equipment manufacturers.

Under the Modified Final Judgment, the operating companies are "prohibited from discriminating between AT&T and other companies in their procurement actitivities, the establishment of technical standards, the dissemination of technical information,...and their network planning."[77] Moreover, the MFJ "...requires AT&T to provide [the] Operating Companies with, *inter alia*, sufficient technical information to permit them to perform their exchange telecommunications and exchange access functions....The Operating Companies, in turn, are prohibited from discriminating in the 'establishment and dissemination of technical information and procurement and interconnection

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[77]Id. at 142.
[78]Id. at 177.

standards.'"[78] Although the Operating Companies are permitted to market equipment, this is justified by noting that "it would be quite difficult for an Operating Company to conspire successfully with a manufacturer to provide advance information about revised network standards or to impose interconnection restrictions which favored that manufacturer's products and no one else's."[79]

The most recent development affecting competition in the telecommunication equipment and services markets is the FCC's decision in its Third Computer Inquiry.[80] The purpose of the Inquiry was to deal with the complaint, raised by AT&T and the Bell Operating Companies, that the costs of providing certain combinations of basic and enhanced services is substantially increased by the Computer II requirement that they be provided by separate entities. Previously, the Commission had, on an *ad hoc* basis, granted waivers to the requirement. In the Third Computer Inquiry, the Commission went further, however, to permit complete relief, but only under certain conditions.

In Computer III, The Commission indicated that it would waive the separate subsidiary requirement if competitors were provided with Comparably Efficient Interconnection (CEI) and, moreover, if an Open Network Architecture plan acceptable to the Commission had been offered. The Commission concluded that "in a network design that uses properly defined open (sic) Network Architecture principles, a technological implementation of our requirements can replace our service-by-service regulation of carrier participation in enhanced service markets."[81]

[79]Id. at 191.
[80]60 RR 2d 603 (1986).
[81]Para. 211.

The requirement of Comparably Efficient Interconnection is intended to provide competing suppliers with access to the telephone transmission system on the same basis as the subsidiaries of the telephone company that are providing the same services. The form of access need not be identical--hence the term "comparably efficient"--but it should not put competing suppliers at a competitive disadvantage.

Open Network Architecture means that the components of the telephone system are to be made available to competing suppliers on an unbundled basis so that they can be combined with the services of these suppliers in any manner that is desired. The nature and identities of these components--the basic service elements--in ONA are likely to be contentious issues since they will affect the potential for competition. Competing suppliers will undoubtedly wish to have highly disaggregated components with which they can interconnect easily. The telephone companies are likely to argue for a higher level of aggregation.

Both the interfaces with the basic service elements and the number and nature of these elements are standards issues. The first involves an obvious standards concern since these interfaces will determine whether a competing supplier can employ a particular element in the services that he provides. Less obvious is why the second is a standards issue. If components can only be obtained on a bundled basis, the interface between them is completely inaccessible to the competing supplier. But the economic effect on a competing supplier of an interface that is inaccessible is exactly the same as if it were accessible but his component is incompatible with it. Providing components only on a bundled basis is the limiting case of incompatibility.

Although the Commission did not define Open Network Architecture, leaving its definition to the industry, it did indicate that "...starting at the time that AT&T and the BOCs begin joint planning, research, or development of enhanced services, they will be required, for all network services or changes to existing network services that affect the interconnection of enhanced services with the network, to notify the enhanced services industry that such a change is planned. Such notification will take place at the time that AT&T or any BOC makes a decision to manufacture itself or to procure from an unaffiliated entity, any product the design of which affects or relies on the network interface."[82] The objective of this requirement is to prevent changes in network design from disadvantaging competing suppliers by providing them with information about such changes on a timely basis.

Two broad lesssons can be drawn from this history. First, the range of services that independent suppliers can offer to telecommunications customers has increased markedly over the last three decades as the restrictions previously imposed by AT&T have been eliminated by regulation. Indeed, the initial impact of many regulatory interventions was either to deny AT&T, and later the BOCs, the ability to provide certain services or to restrict the way in which the services could be offered.

Second, the elimination of the restrictions placed on the provision of services by the telephone companies is being conditioned on the imposition of behavioral constraints designed to facilitate competition

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[82]Para. 252.

from independent suppliers. These constraints include requirements that information about network design changes be promptly provided to competing vendors, that these vendors be provided with interconnection to the telephone system that is "comparable" to that provided when a telephone company itself offers a service, and that the components of the network be available on an "unbundled" basis so that customers can acquire from the telephone companies only those portions of network services that they desire.

7. THE DETERMINATION OF TELECOMMUNICATIONS STANDARDS

This section examines two cases of standard setting in telecommunications. The first, national uniformity in Open Network Architectures, illustrates how, if the Bell Operating Companies fail to coordinate standard setting for ONA, its adoption may be inefficient. The second, ISDN standardization, discusses how standards may affect competition in the future ISDN marketplace.

a. National Uniformity in Open Network Architectures

In Section 4, we discussed why, if standard-setting is carried out non-cooperatively, a new technology that everyone regards as superior will not necessarily replace an older one as the standard nor will a new standard that does emerge necessarily be the most efficient one. An illustration of the possible difficulties resulting from a lack of coordination in standard-setting concerns the manner in which the BOCs are establishing standards for their Open Network Architectures. Although there have been discussions of the need for national uniformity, and some large telecommunications users have expressed concern that lack of uniformity will increase their costs, there is presently no formal mechanism to coordinate the standards that will be used in the various regions of the United States.[83]

Because different BOCs may have different preferences -- perhaps because they have greater experience with some technologies than with others -- or because without a coordinating mechanism different technologies may be employed even in the absence of such preferences, the outcome may be: (a) the absence of a national standard and the resulting slow development of new technologies, because users who operate in different regions find the costs of employing different standards too costly; (b) the simultaneous use of incompatible technologies in different regions, with higher costs and lower benefits for users; or (c) the emergence of one technology as the standard through a "bandwagon" in which those BOCs using other technologies are forced to switch to the standard.[84]

A uniform national standard may fail to develop rapidly if users, uncertain about whether a national standard will emerge and what that

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[83] Betts (1986) describes a large user who "is worried that the lack of standard protocols will increase cost for equipment, staff expertise and software and complica*e operating procedures as well as hamper the diagnosis and resolution of network problems" and quotes the counsel for the International Communications Association, a group of large users, that "We have an overall concern that we may end up with seven separate, incompatible, ONA plans."

[84]Note that this discussion assumes that any preference by a BOC for a particular standard depends only on the direct benefits from the sale of services. It is possible, however, that a particular technology may be favored because it reduces the competition that a BOC faces from suppliers of equipment that compete with equipment offered by the BOC, or because it reduces the ability of other suppliers to offer equipment that provides services that could otherwise be offered through the network. These issues are discussed below. We should observe, however, that the proposed European policy to achieve common standards among countries (Commission of the European Communities (1987)) is based primarily on a desire to promote competition.

standard will be, adopt a "wait and see" posture. If the fear of being stranded with the wrong technology results in such behavior by a large number of users, "excess inertia" may result.[85] Recall that this outcome is possible even if users greatly value having a common standard.[86] If this were the case, a coordinated standard-setting process might be able to overcome the inertia. Such an outcome is especially likely if all BOCs would be better off under national uniformity but, even in that case, difficulties of coordination will exist if the distribution of benefits depends importantly on which technology becomes the standard.

A second possibility is the rapid adoption of incompatible technologies in different regions. This is likely if there are many customers whose communications are confined to a single region, so that incompatibility is unimportant to them, and/or if the benefits of using the new technologies exceed translator costs for users who communicate between regions. Note that, although the new technologies develop rapidly in this case, the cost of incompatibility to users -- in terms of translator costs or services not used because their benefits are less than the cost of translation -- may still be substantial and the outcome may be less efficient than if there were a common standard.

Third, one technology may emerge as the national standard. This can occur if a bandwagon that is started by early adopters produces changes in the offerings of those BOCs using other technologies. Once

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[85]Such inertia can also result if the benefits to users are reduced because incompatibility raises their costs.

[86]Besen and Johnson (1986) conjecture that the absence of an AM stereo standard may be responsible for the slow rate of diffusion of that technology by radio stations and listeners.

again, however, it is important to observe that the winning technology is not necessarily the one that is most economically efficient.

Finally, of course, the BOCs may agree on a common set of standards. As we noted in Section 2, two conditions seem especially important for this to occur. One is that there are no important differences in the preferences of the various operating companies, which may exist here as long as none of the BOCs has made significant investments in a particular technology. The other is that the growth of the market is highly dependent on the existence of a common standard because users place a great value on compatibility. If both conditions are present, standards may be result through agreements among the BOCs. Recently, the Exchange Carriers Standards Association announced formation of the Information Industry Liason Committee to "act as an ongoing national forum for the discussion and voluntary resolution of ONA issues."[87]

We do not mean to suggest that absence of a formal mechanism to achieve national uniformity will necessarily produce inefficient outcomes, or that the existence of such a mechanism will always overcome these inefficiencies. However, the main lesson of the theory discussed above is that there is no guarantee that uncoordinated standard setting by the BOCs will achieve the efficient outcome and that there are many instances in which it will not. Moreover, it may be difficult to tell even after the fact whether the outcome is an efficient one. The emergence of a common standard and rapid diffusion are still consistent with the choice of the "wrong" technology.

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[87] "ECSA Sponsoring Information Industry Liason Committee on 'Open Network Architectures," 53 *Telecommunications Reports*, October 19, 1987, p.15.

b. ISDN Standardization

A worldwide effort, involving literally thousands of individuals, is currently underway to develop standards for ISDN.[88] The technology promises, as its name indicates, transmission of various types of information--voice, data, video, and facsimile--in digital form over a single integrated network. Not only will the network accomodate a wide range of services but it will be able to employ the same communications paths to accomodate different types of information. In order to engage in these functions, an ISDN will have the capacity to manipulate information to facilitate its transmission.[89] Although elements of such networks currently exist, the changes that ISDN will permit are likely to alter fundamentally both the United States and international telecommunications systems.

At one level, the standardization issues involved in ISDN are similar to those discussed in Sections 2 and 3 of this paper which examined why suppliers may seek to standardize their services to increase the value of their offerings to consumers. Thus, the countries involved in attempting to set ISDN standards through the CCITT are interested in achieving compatibility among their various national telecommunications networks. As we have already seen, however, even where compatibility is highly valued, it may not be easily achieved. The principal reason is, of course, that, although all countries may

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[88]Rutkowski (1985) contains an extensive description of this effort.

[89]The neutral term "manipulate" is used here to avoid prejudicing the question of whether these activities fall into any existing regulatory categories.

value compatibility, they may not agree on what the single standard should be. As a result, some differences among national systems may persist.[90] A similar issue arises where the standards preferred by those concerned primarily with the transmission of voice traffic differ from the standards favored by those involved in data transmission.[91]

In attempting to achieve standardization among national ISDNs, the CCITT has not confined its activities to the specification of a single dimension of each interface through which information can move. Instead, it has pursued a strategy of attempting to achieve compatability at a variety of "layers," ranging from the physical interconnections that will be permitted to the forms in which data will be recognized. [92] Because communication must be effected at all layers at each interface, the specification of standards is quite complex.

Moreover, not only are the various interface specifications being specified but so is the architecture of the ISDN. This means that the standards will encompass where the interfaces will be and whether they will be accessible by users or independent suppliers. Clearly, the more alike are the various national systems the simpler and less costly will be the required interfaces between them. But the fact that the architecture of ISDN will be specified by CCITT may create problems in those countries, like the United States, where there are a large number of competing suppliers of telecommunications services.[93]

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[90]It may also be the case that some countries may prefer a degree of *incompatibility* in order to shelter their domestic telecommunications suppliers from foreign competition.

[91]See, e.g., the comments of IBM filed in response to FCC, *Notice of Inquiry*, 94 FCC 2d 1289 (1983). The comments are contained in GEN Doc. No. 83-841.

[92] These layers are patterned, to a substantial degree, on those in the Open Systems Interconnection (OSI) Reference Model.

[93]Although not as far along as in the U.S., this development is also occurring in the United Kingdom and Japan.

In Sections 5 and 6, we discussed how the terms on which network access is available to independent suppliers can affect the extent of competition in the provision of information services. Here, the concern is whether the design of ISDN, in particular restrictions on user access, can be used to limit the competition faced by the operators of the transmission network. As a result, there may be significant conflicts between users and suppliers. Rutkowski (1985, p. 46) puts the point succinctly: "...users generally have an interest in maximizing their service options, while providers (particularly telephone network providers) have an interest in limiting those options to maximize their operating efficiencies and minimize losses to competitive providers."

From the perspective of establishing standards, the most significant aspect of the development of ISDN is the increase in the number of interfaces at which access to the telecommunication network can occur and the ways in which such access can take place.[94] Where before the Carterfone decision "access" was available only at an AT&T-supplied terminal, subscribers, or providers of enhanced services, can now obtain access to the system at a number of points using a number of different types of equipment. ISDN is likely to further increase this number. However, a significant degree of standardization of interfaces and terminals must be accomplished for this to occur.

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[94]The introduction of Open Network Architecture in the United States will have a similar effect. A recent article argues that the effect of ONA is likely to be an increase in the number of interfaces by "an order of magnitude." See Editorial, "Part 68 Is Not Compatible with ONA," 21 *Telecommunications*, North American Edition, January 1987, p.8.

Consider a message that must "access," i.e., pass through, a particular node in the telecommunications network if it is to reach its intended destination. To obtain access, a number of components are required to establish a "path." The first such component is the subscriber's terminal equipment. This can be either a device with a standard ISDN interface, e.g., a digital telephone, or one that requires an adapter to access a digital network. Second, there is network equipment required to perform switching and concentration functions. An example of such a device is a digital exchange. The third type of component is network termination equipment that lies between the transmission system and the subscriber's premises. It is the connection between the subscriber's premises and the local telephone loop. Certain types of equipment permit the second and third components to be combined. Finally, there is the link between the local loop and the network itself.

The subscriber can employ these components in various ways and, depending on the regulatory regime, may choose to obtain many or few of them from the telephone company. In the United States, for example, a subscriber might employ a terminal requiring an adapter, as well as the adapter and both types of termination equipment from the telephone company.[95] Alternatively, he might obtain the adapter from an independent vendor and the termination equipment from the telephone company. Or, he might also purchase the "switch" from an independent vendor and only the last link from the telephone company. Or he may

[95]Conceivably he might purchase the various components from different parts of the company.

acquire all of the components from independent vendors. Similarly, a subscriber may employ a terminal that does not require an adapter but may purchase any or all of the remaining components from independent vendors.[96]

Significantly, the ISDN model currently under consideration does not contemplate an interface at which a subscriber, or an independent service provider, can obtain access to the system without employing the telephone company's local loop.[97] This is consistent with the views of most PTTs and, probably, with those of the BOCs, which would like to require use of this loop. It is not, however, consistent with the views of independent suppliers who wish to maximize the number of points at which they can obtain access so that they can employ as much or as little of telephone company-supplied services as they desire. Thus, even if there were no controversy about the designs of the interfaces that were actually offered, there might still be a dispute over where and how many were offered.[98]

United States policy is likely to vary from international ISDN standards if the latter do not permit access to the network without use of the local loop. For example, U.S. vendors can expect to obtain access through the telephone company network and, indeed, there have even been discussions of whether Comparably Efficient Interconnection

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[96]Of course, this wide range of options is available only where competitive suppliers exist. In many countries, all components must be acquired from the telephone company.

[97]In the language of CCITT, this is not a "reference point." See Rutkowski (1985, pp. 145-146.)

[98]Note that denying access is equivalent to providing an interface that is totally incompatible with the equipment of one's rivals.

requires that the equipment of these vendors be located at telephone company central offices.[99] One continuing policy concern is thus likely to be which interfaces are available to independent suppliers and on what terms.

One way to assuage this concern is for the telephone companies to provide, as they are currently required to do, unbundled private line service, i.e., pure transmission capacity, along with ISDN.[100] Thus, ISDN would not completely replace the existing telecommunications system, but some elements of the old system would remain. As a result, independent suppliers would have substantial freedom to construct their own networks using telephone company-provided private lines and other components of their own choosing. These systems would employ none of the "intelligence" in the telephone company's ISDN but would be able to provide many, or all, of the same services. As a result, even if all of the elements of an ISDN were not available on an unbundled basis, enough other resources could be available to make feasible the provision of competitive offerings. This would also provide protection to competing vendors against the possible manipulation of the design of interfaces for strategic purposes. Thus, although a requirement that private line service continue to be provided does not appear to be a standards issue, it may be a partial substitute for complete agreement on standards.[101]

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[99]Note that denying access to independent vendors at the central office may be equivalent to the strategy, discussed by Ordover and Willig (1981), of not making certain components of a system available to rivals, depending on the costs of the alternatives.

[100]This is apparently contemplated by the CCITT but, in any event, it is likely to be an element of United States telecommunications policy.

[101]Alternatively, it can be thought of as providing an alternative interface. It should also be noted here that the pricing of private lines as well as of competing telephone company offerings will affect the nature of competition. As Ordover and Willig (1981) note,

Still another way to prevent carriers from using standards in an anticompetitive manner is to limit their ability to provide certain types of services, or to limit the way in which they may do so.[102] However, as we have already noted, drawing the line between the provision of basic (transmission) and other services is becoming increasingly difficult. It will become more difficult with the introduction of ISDN, where the network itself will contain a substantial amount of intelligence. Moreover, economies may be lost if such restrictions are imposed. In any event, existing restrictions are being relaxed, so that competition between exchange carriers and independent service suppliers is likely to increase. The result is that these suppliers will remain concerned about where they can obtain access, and what the nature and terms of that access will be. Regardless of how ISDN standardization issues are resolved by the CCITT, these issues are unlikely to go away any time soon.

The international standard-setting process for ISDN is intended to produce a set of standards to which all nations will conform. Achieving such conformity is a relatively straightforward matter in those countries where a single entity, the PTT or a franchised monopoly, provides all telecommunications services and equipment and thus determines all aspects of the telecommunications technology that is used. It is likely to be difficult in countries like the United States

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"underpricing" components that compete with those sold by rivals and "overpricing" components that are needed by rivals may be part of a competitive strategy. Thus, even if private lines are available, they will not be an attractive alternative to ISDN if they are very costly.

[102]This is, of course, the approach taken in *Computer II* and in the *Modified Final Judgment*.

where, to an increasing degree, communications services are provided by independent suppliers who must use part of the telecommunications system to do so.

Standardization issues will remain contentious in part because changes in technology, as exemplified by the introduction of ISDN, are serving to further blur distinctions between transmission and other telecommunictions services. As telephone carriers provide additional services, they will increasingly compete with other firms that need access to the telephone system. Among the areas in which the interests of the carriers and these firms will conflict are the nature and design of network interfaces. The problem is more complex than achieving compatibility between nuts and bolts. Imagine that suppliers of bolts want their products to be able to "interface" with a wide variety of nuts, that the the suppliers of nuts want to be able to provide nuts and bolts in any combination and *not* to offer certain types of nuts separately, and that the supply of nuts is regulated and you have some picture of the standardization issues faced by the telecommunications industry now and in the indefinite future.

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