Technical Standards and Technological Change

in the Telecommunications Industry

by

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ABSTRACT

Innovations often involve complex networks or systems. Components of an interdependent technological system require interface standards or "gateway technologies" for the attachment of basic equipment and/or use of inputs. Alternatively, standardization (interchangeability among components) also yields compatibility. The emergence of standardization or gateway protocols both have implications for market demand, production costs and the strategies of pioneering innovators and their followers. Here we analyze the role of standards specification in the telecommunications industry. Graphics protocol standards for videotex, compatibility standards for microcomputers, and technical standards for computer networks are used to illustrate how competition, cooperation, and coercion can affect efficiency and innovation in telecommunications.

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I. Introduction

While OPEC and the energy crisis symbolize the economic forces of change in the U.S. during the 1970s, the AT&T divestiture and the associated telecommunications revolution may well be chronicled as the major economic developments of the 1980s. Innovations in the telecommunications industry have given rise to a number of major technological developments, especially in signal delivery systems.[1] Components of such complex technological systems require compatibility (interface) standards for the attachment of basic equipment and the use of inputs. However, with telecommunications opened to new entry for voice, video, and digital transmission, and with the traditional links between the provision of local telephone service and other services cut, the potential for incompatibilities is serious. Thus, telecommunications deregulation, along with changes in radio spectrum management and the development of new services, raises questions about the relationship between technical standards and economic performance.[2]

We know that competition and innovation will both be affected by the standards-setting process and the technical protocols which may emerge from the process. In some cases, *de facto* compatibility may enhance innovation at the expense of price competition; in others standardization can promote some entry, but exclude potentially attractive technologies from the market. Because it is difficult to determine *a priori* which types of standards and which

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standards specification processes are socially beneficial and which are not, a better understanding of the trade-offs among compatibility, competition, and technological advance seems imperative for well-directed policy in the future.

The purpose of this paper is to illustrate how technological innovations have affected private initiatives and public policies in the area of setting standards. The three case studies provide some insights as to whether we are devoting too many or too few resources to the standards specification process in telecommunications. In addition, the discussions of videotex protocols, computer interfaces, and networking standards illustrate how technological opportunities interact with institutional structures for the resolution of standards issues.

The first case study examines teletext and videotext systems. These systems enable enhanced transactions services, such as home shopping and banking. Compared with government authorities in Europe and Japan, the U.S. Federal Communications Commission has not taken an interventionist role in the standards-specification process for this technology. Such "benign neglect" may (or may not) have been a good strategy, given the strengths and limitations of private competitive (and cooperative) activities in this market.

The second case study, technical standards affecting computer interfaces and operating systems, provides additional historical insights regarding how industry performance is affected by government refraining from mandating compatibility standards. In rapidly changing technological fields, premature standardization (imposed from outside the industry) could dampen incentives to innovate, even though such standards would provide a focal point which reduced uncertainty for both suppliers and demanders.

The third case study describes how networking standards are evolving, particularly in the context of international markets. Here, the interconnection of computers reflects even more complicated compatibility issues than those raised by videotex and by different computer operating systems. However, here the development of networking protocols raises the possibility of linking computers which may have very different operating systems. Thus, technological advances in networking protocols illustrate how standards specification can resolve technical incompatibilities without requiring standardization among all components of the system.

After presenting these telecommunications case studies in Section II, the next section discusses several lessons which emerge from these studies. The focus is on the joint roles of innovation and standardization in the context of network technologies. Network technologies are characterized by increasing returns in production or use and a substantial amount of technical interrelatedness among (durable) system components. As defined by David and Bunn (1987), "gateway technologies [permit] the technical interconnection of system-components that would otherwise remain isolated" (p. 3). Such technologies achieve ex post technical compatibility in the absence of standardization.

David and Bunn analyze the pivotal role of the "rotary converter" in the context of electricity networks. The device, patented by Bradley in 1887, was used to transform direct electrical current into alternating current (and vice versa). The converter had dramatic effects on the subsequent development of electricity systems: although it served a technically neutral function, allowing passage in either of two directions, the gateway technology had a non-neutral impact on the alternative technologies--leading to the ultimate adoption of alternating current for electricity generation and transmission. The telecommunications and computer networking issues discussed here are still in the process of being resolved, so we cannot fully evaluate industry performance.

Section III turns to the impacts of key participants and "third-party" entrants who develop gateway technologies in new industries. Some important lessons have emerged from historical experiences. For example, induced innovations can reduce competitive pressure for improvements in incompatible systems which are sponsored by rival firms (as happened with Edison General Electric and Westinghouse). In addition, the creation of gateway technologies (or protocols) can reduce incentives for standardization.

After reviewing lessons from recent telecommunications experiences, the paper concludes with several policy recommendations. In general, the case for mandating standards is weakest where the particular technology has diverse uses (as do both communications and computer systems) and where technologies are undergoing rapid change. Nevertheless, government action which establishes a "focal point" can promote efficiency, especially when no technology is clearly preferred by the ultimate demanders.

II. Case Studies from Telecommunications

The relationship between standards specification processes and innovation is complex, whether the process involves competition, cooperation, or coercion. The slow penetration of videotex in the United States stems from both delays in the standardization of technical protocols and from the extensive substitutes available in this economy. Rapid growth in computer usage and technology occurred without significant government intervention, despite incompatibilities among competing operating systems. Finally, networking standards further illustrate how difficult it is to identify clearly preferable standards for sharing resources over computer networks. First, let us examine each type of system to see the role of standards in promoting innovation.

A. Competition in Teletext and Videotex

Teletext and videotex technologies involve the provision of additional services via television signals. Both technologies involve a host computer, a communication linkage system, data bases and home terminals. In a teletext system, viewers receive frames, while in the videotex system, users interact with data bases. Competing signal transmission technologies include broadcast TV (from ground or satellite), telephone, and cable. Similarly, receiver/adaptors range from simple television attachments to complex home computers. These two technologies illustrate the demand interdependencies that complicate the standards determination process. Furthermore, they reveal how a government agency, the FCC in this case, can affect the development of the relevant standards.

Some analysts see these technological systems dramatically altering market transactions, as in shopping and banking by terminal. However, market penetration has been relatively slow in the United States, with the demand for the product and various services associated with it being not well understood. Is the standards process a bottleneck for market penetration? Some analysts maintain that the issues are more economic than technical: even with compatibility standards, the markets just may not exist, given the competition from overlapping services. Developments in Britain and Japan illustrate conflicting perceptions of the ultimate market for such network services, which have led to different systems (involving different protocol/information requirements).

Other nations that have experienced successful market penetration of similar technologies have usually relied on major government commitments. For example, the British Prestel system is a major operational system similar to teletext, although the standards (or protocols) used for that system differ dramatically from those proposed in the United States (Tyler, 1976). The two systems differ in terms in error detection, redundancy, hardware dependence, memory usage, and image complexity. For example, the coding scheme (and required information) determines the decoding required by the terminal (system overhead) and whether the conceptual content of the information is retained. Since production costs and customer valuation will both depend on which standards are adopted (and whether competitive systems are incompatible), the debate over which standards to adopt has potentially significant resource allocation impacts. For example, premature standardization on a simplistic teletext system might jeopardize later acceptance of a more sophisticated videotex.

The question is what (if any) teletext or videotex system will ultimately prevail in the United States. Similar questions are asked by manufacturers of component technologies in all countries. For these two technologies, the FCC has adopted a policy of leaving the selection of protocols to voluntary cooperation and market forces. AT&T has offered NAPLPS (North American Presentation-Level Protocol Syntax--derived from the French Antiope and Canadian Telidon protocols) as the standard for interactive systems. IBM-Sears-CBS formed a joint venture in videotex which is expected to support NAPLPS. Although IBM's prior entry in videotex was Prestel-oriented (for the European market), CBS was instrumental in the compromises yielding North American Broadcast Teletex standards (NABTS) compatible with NAPLPS. Since IBM and AT&T will be battling for position in this new industry, implementation issues associated with the technical standard may play a role in the viability of the new industry.[3]

Note that because Europe and Japan are developing potentially incompatible standards, international considerations are important for videotex. The European Postal and Telecommunications Council has several levels of standards, from alphamosaic (a technique using small squares) to alphageometric and alphaphotographic (covering the bit-plane). The Japanese CAPTAINS system has a bit-plane standard (partly because of the complexity of Japanese characters). There are many levels within each system and great cost (and quality) variance. Although the protocols differ for the European and North American standards, the latter seems to be winning out. The problem of international standards is underscored by the fact that multinational firms must compete in several markets.

However, standards are not the only factors affecting the size of a market. Regulatory decisions in early 1983 determined some technical features of teletext transmission and its treatment as a subcarrier service. The FCC established the portions of the vertical blanking interval which would carry teletext signals. It also ruled that cable systems would *not* be required to retransmit teletext in conjunction with regular video signals. As a consequence of this decision, broadcasters cannot guarantee advertisers a large home audience. In the case of interactive systems, the corporate market for videotex is likely to be most important in the short run. However, the opportunities for residential applications are substantial if regulatory decisions are conducive to the creation of a large enough market.

Note also that competing standards need not result in fragmented markets and a smaller aggregate demand if incompatible standards can be reconciled via a gateway technology such as a universal chip decoder. Already, suppliers are offering translator integrated circuits which allow the North American protocol (NAPLPS) to interface with the Prestel system. Thus, achieving unanimous agreement on a standard is not crucial if low-cost translators are available. This development suggests that standards committees in areas susceptible to integrated circuitry might do well to specify *families* of standards, so basic equipment manufacturers could move forward and third-party interface manufacturers could focus on their gateway technologies.

In the past, the FCC tended to select a *single* standard when confronted with competing protocols and associated technologies (as with standards for color TV in 1950, which were reversed in 1953). Under the FCC's current deregulatory stance, factors in the competitive marketplace have been allowed to dominate the process. Consider the FCC's decision on Zenith's TV stereo transmission system (supported by the Electronic Industries Association). Broadcasters and cable operators favored a *decision* on stereo TV (rather than letting a winner emerge via the marketplace). Intervention by the FCC has some justification: the scarce radio spectrum requires either private ownership or public allocation to avoid broadcast externalities. Nevertheless, the FCC did not mandate a standard. It did "protect" (bless) the industry-preferred Zenith standard, but allowed others to develop. Hence, the FCC accepted a "focal point" technology. The same basic issue confronted the FCC for stereo AM radio, where it again decided to let competitive (incompatible) systems operate (see Berg 1987).

In the United States, regulatory emphasis on market forces is somewhat controversial. For example, Sterling (1982) has expressed concern with this approach. He sees the dramatic increases in claims on the spectrum as possibly requiring greater FCC regulation and tighter frequency-preserving standards. This view is not inconsistent with FCC policy: once the performance parameters are set, let the market select technical protocols. In the process, standards associations may be key players, but the emphasis would be on voluntary cooperation rather than coercion. Such an approach presumes that negotiation costs are small relative to the group benefits and that competitive relationships will not be unduly disrupted.

The choice of the appropriate institutional mechanism for promoting compatibility is a complicated one. The bottom line is that the choice between imperfect competition and imperfect regulation must be based on historical experience rather than theory which is divorced from real-world constraints. Longley's (1968) review of how the FCC shifted the FM broadcasting band in 1945 suggests that the technical factors (signal propagation interference) were less important than political and economic factors (one-half a million FM receivers were made obsolete to obtain another low band channel for the infant television industry).

However, even when economic considerations clearly dominate the FCC debate, ultimate decisions need not promote resource allocation improvements. Webbink (1969), in his evaluation of the 1962 All-Channel Television Receiver Law concluded that the attempt to promote UHF television lead to significant inefficiencies. Recent FCC decisions on stereo AM, teletext, and other issues represent experiments in letting new technologies face the market rather than government agencies. The current emphasis on market forces and consensus standards represents a major shift in FCC policy. Unfortunately, theory by itself is not an adequate guide for evaluating the legitimacy of this shift. Since we have no theory of imperfect governments, we need a case-by-case review of how the government tends to intervene in comparable circumstances. For an excellent start on such an enterprise, see Besen and Johnson (1986) for a comparison of U.S. experiences in eight technologies: AM stereo, TV stereo, teletext/videotex, color TV, TV program scrambling, direct broadcast satellites, high definition TV, and cellular radio.

B. Computer Interfaces and Operating Systems

The computer industry provides yet a second example of how standards, costs, and demands interact. For example, rules and conventions describe how data should be formatted so that when a terminal receives information, processing and display functions can proceed smoothly. As more specific requirements are incorporated into a standard (as with NAPLPS), the "compliance" costs rise for some firms (unless gains from variety-reduction and scale economies overcome the costs of add-ons). For example, complicated protocols require certain system overhead, which constrains other system capabilities. Apple's MacIntosh system differs from IBM's system, although gateway technologies are emerging which allow the former to emulate the latter. Thus, manufacturers and consumers face trade-offs when making production and purchase decisions.

To illustrate the range of issues which arise in computer standards, consider the RS-232C interface (a term familiar to microcomputer enthusiasts).[4] The technical title of the standard is "Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Interface." Although widely accepted, the RS-232C standard for communicating between terminals and printers has some limitations which technical groups are now trying to sort out. Yet without such a standard, compatibility among microcomputer components would be severely limited.[5]

The case of microcomputers illustrates how pioneers, producing the first product with wide distribution, usually set technical interface standards. For example, the number of pins on connectors in microcomputer systems was originally set in the mid-1970s by Altair, the first hobbiest microcomputer. The Altair system for making electrical connections over a group of common lines ultimately became the industry standard (in modified form) and was given a generic name to prevent confusion (and to ensure that no company had a special advantage). Its S-100 bus (now the IEEE 696 bus) became the norm.

Furthermore, in the case of the IEEE 696 bus, the standard not only determined the number of pins, but the function of each pin (and data transfer protocols). The technical features of particular protocols (discussed by Garetz (1983)) is beyond the scope of this paper. Suffice it to note that this kind of standard has downward compatibility (in that all the pins do not have to be used) and even upward compatibility (some pins are reserved for future assignment and others are available to manufacturers for specific applications). In this sense, a standard is like a potentially private good whose ownership assignment is handled via technical committees. Just as the radio spectrum is a scarce good whose allocation affects the wealth of firms, assignment of functions to pins (or specification of protocols) can give advantages to one firm. Furthermore, compatibility might be achieved not through standardization, but through interfaces incorporating translator chips, jerry-rigging signal protocols, "fooling" the system, etc. Thus, standard *specification* may be as important as standard selection, to the extent that the former completely articulates characteristics which would be needed for an interface (gateway technology).

Not all computer standards are hardware-specific, but they generally have implications for hardware design. Brock (1975) has presented case studies of two attempts to develop standards in the computer industry: COBOL (Common Business Oriented Language) and ASCII (American Standard Code for Information Interchange). The motivation for the first effort was to facilitate the exchange of programs across different computer systems. The second effort involved lowering the cost of exchanging data among systems. Both illustrate the problems associated with trying to standardize during technologically dynamic phases of the industry's history.

Computer users with business applications had an interest in the development of a language that would not be machine-dependent, so the same programs could be run on different computer systems. In the late 1950's, the rise in programming costs relative to computing and memory costs put a premium on program compatibility. With the Department of Defense taking the lead, a Conference of Data Systems Languages (CODASYL) met in 1959. RCA and Univac saw this effort as strengthening their positions vis-a-vis IBM, while the dominant firm announced that it would not support COBOL, the new language. As a major buyer, the Government Services Administration pressed for COBOL in the early 1960s. In 1968, the American National Standards Institute (ANSI) approved a national standard COBOL, but variants remained. Nevertheless, the efforts of CODASYL illustrate how user groups (and key buyers) can influence compatibility.

The effort in the area of data exchange also began in 1959 and again was slowed by the opposition of IBM. Data exchange is affected by coding schemes, in which characters and decimals numbers are represented by binary numbers. These representations were closely linked to machine designs, so the manufacturers had vested interests in particular schemes. IBM, in particular, preferred its EBCDIC code for its series 360 machines. Earlier IBM machines had used a six-bit binary number representation; the EBCDIC system was consistent with the earlier one. The American Standards Association supported ASCII, which involved a sorting sequence partially incompatible with the earlier IBM system. Additional hardware or software would be needed to achieve compatibility. IBM voted against ASCII in 1962, and

EBCDIC continued to be the de facto industry standard. However, in this case, Control Data and Honeywell also opposed ASCII.

Finally, in 1968, President Johnson issued a memorandum establishing ASCII as a federal standard for federal purchases (including its use in magnetic tape formats). However, IBM pushed to confine ASCII to an interchange code, so it would not be required as an internal code. IBM succeeded in this effort, and continued to market non-ASCII (and even non-EBCDIC!) systems. Whether this behavior reflected the costs of variety-reduction or strategic behavior by a dominant firm is unclear.

An even more fragmented situation has emerged in the area of actual operating systems for mainframe computers and their micro-counterparts. Standards for operating systems of microcomputers (associated with the various 8, 16, and 32 bit processors) have emerged via the competitive marketplace. The lack of standardization among microcomputer operating systems and the existence of many versions of the BASIC language reflect a similar set of strategic considerations for firms. In some situations, the cost of "giving up" a standard (such as an idiosyncratic language) may be very high for a firm, since the unique features of the machine may not be accessible through "traditional" BASIC. Agreement on lower-level protocols for signals is one thing, agreement to limit your product is another. The evolution of the microcomputer industry is described by Hergert (1987) who documents the role of IBM in setting de facto standards with its PC. He sees reduced consumer search costs as a major benefit of compatibility within a series of product lines, while noting other dimensions of the standards question: retraining costs which arise when standards or software changes, network externalities (Katz and Shapiro, 1985), switching costs (Farrell and Saloner, 1985), inventory costs (for distributors), and meeting particular preference patterns. According to Hergert, "the IBM standard can be generalized to include the floppy disk format, keyboard layout, printer interface, video display, cables, hard disk format, modems, memory chips, and other components of the system" (pp. 77-78).

As has already been noted, different generations of operating systems also have resulted in incompatibilities over time, so that some software designed for the PC cannot be run on the

IBM AT. Thus, compatibility can be a matter of degree, rather than an all-or-nothing variable (Berg, 1988). When IBM PC clones cut dramatically into IBM's market share, the decision to shift to new standards in PS/2 represents a resumption of IBM's strategy to shake up the market when its product becomes a relatively undifferentiated commodity.

Presumably, one of the motivations behind much R&D in computers is to alter production trade-offs and reduce the cost disadvantage of nonstandardization. Yet the demand disadvantage may still be present, if consumers perceive high costs to obtaining compatibility. Such problems lead some firms to consider the collective determination of standards. For example, Gabel (1987) describes the efforts of ten European computer manufacturers to create open standards based on the "UNIX" operating system -- in opposition to IBM's proprietary standards. Given the links between home computers and likely videotex and networking demand, we need to ask whether the government should have tried to play a greater role in promoting a single standard.

Debates over standards for microcomputers need to recognize that compatibility may not be a highly valued objective when the nature of the new product is relatively unstable compared to when products are in more mature phase of the product life cycle. When the technology is relatively stable, compatibility may have a lower cost (in terms of opportunities foregone). In some cases, standards are obsolete even when they are announced. For example, the MSX standard offered by the Japanese for 8-bit home computers emerged at a relatively late date. The need for such a standard had already been superseded by technologically more advanced microcomputers. Thus, the question to be asked is whether a "Czar of Microcomputing" really could have done a more masterful job than has emerged via the competitive marketplace.

C. Networking Standards

Another issue has arisen in the context of technological opportunities in networking, from local to transnational. Again the roles of dominant firms, regulators, and politics become intertwined. The problem is how to balance compatibility among components against flexibility that facilitates continued innovation. There are two kinds of networks raising compatibility issues: local area networks (LANs) for computers and integrated services digital networks (ISDN) for telecommunications. Both types of networks will be major factors affecting computer applications in industry over the next decade.

Examples of Local Area Networks abound on campuses, in corporate headquarters, and throughout production facilities. By interconnecting computers, input devices, output devices, and other peripherals, LANs permit data files and other information resources to be shared by many users. The standards issue is whether network architecture will permit different suppliers to serve the market. For example, simple interface devices may enable interconnection among products with high degrees of non-standardization within a LAN.

As described by Young (1983), communications tasks can be broken down into various layers (or subtasks) ranging from the purely physical connection and data protocols, through network switching and data transport, to higher levels (message segmentation, commands, and actual applications--like on-line banking). The International Standards Organization has promoted the layered approach so complete system redesign will not be necessary as technological advances hit the various levels (and to weaken market power that might emerge at any particular level). The associated protocols can be modified to maintain compatibility.

Detailed consideration of the alternative proprietary systems would take us far afield. Suffice it to note that IBM, WANG, Xerox and others offer or are developing proprietary LANs. Some of these now function, especially in retailing (grocery stores and chains). These stand in sharp contrast with proposed open networks based on voluntary consensus standards. The various systems vendors have essentially promulgated families of standards--and (according to Young) these are being ratified by standards organizations. For example, the Institute for Electrical and Electronic Engineers (IEEE) technical committees have members from user-groups and vendors, plus international representatives. Young concludes that the National Bureau of Standards has paved the way for much cooperation within the IEEE committees. In fact, a NBS demonstration of prototype office and factory automation networks (the latter involving General Motors) implement standards needed for multivendor networks. Young views the NBS as making significant contributions towards stimulating private investments in R&D: formal procedures are particularly important when the technology and preferences are not well understood. LAN interface chips which incorporate the IEEE standards for various network layers are coming onto the marketplace: the resulting compatibility ought to enhance competition and facilitate the achievement of economies.

Integrated services digital networks (ISDNs) use telephone lines, cables, optical fibers, microwave radios, and satellite links, to transfer data to distant points. The similarities with LANs are many, but ISDNs are international in scope and involve telecommunications carriers (usually owned by governments). ISDNs integrate traditionally analogue (telephone) systems with digital services in one digital network. As with Prestel vs. NAPLPS, developing standards in an international context is a complicated process. Collins (1987) documents the areas of conflict and cooperation within the European community -- noting that the benefits of cooperation tend to occur over a long time horizon, while the costs (and lost strategic advantages) are borne by suppliers immediately.

The primary technical group involved in standardization is the International Telegraph and Telephone Consultative Committee (CCITT), part of the International Telecommunication Union. The Department of State is the official U.S. representative, with technical inputs provided by numerous groups, including firms, the FCC, the Defense Communications Agency, IEEE, and ANSI. The technology itself is stable and fairly mature, so the development of a performance oriented standard seems feasible. However, without existing systems to crystalize technical issues, the interest in standards has come mainly from carriers rather than equipment manufacturers. Perhaps this reflects an interest in moving enhanced services back into communications network functions.[6] Besides triggering equipment/network disputes, the emergence of new technological opportunities raises difficult coordination issues at the international level.

The Director of the CCITT has stressed the role of standardization in ensuring continuity--both for delivery technique and for the basic service itself (Burtz and Hummel, 1984). Yet the clash between innovation and continuity is clear, especially when the definition of "essential services" (vs. enhanced services) is elastic. The problem is particularly troublesome, given the role of developing countries, whose votes are potentially important in international forums.

III. Lessons to Be Learned

Developments in the three related areas (videotex,computers, and networking) are consistent with Besen and Johnson's overview of lessons from standards experiences in broadcasting and recent theoretical analyses of technical compatibility standards. These relate to the circumstances under which formal standard setting is likely to be particularly important, how firms sometimes coalesce around "focal point" technologies, and the dangers of premature standardization. In addition, the authors emphasize the role of market demand as a determinant of the success of new technologies, the importance of specialized uses for standards adoption, the disproportionate influence of firms at concentrated stages of production, and how homogeneity of preferences (and nonproprietary technologies) promote agreements on standards.

Braunstein and White (1985) expand the gains to compatibility to include "portfolio savings" (where systems users desire to sample from many present and future services), avoidance of user-borne interface costs (including down-time for transshipment), basic equipment savings (no need for duplicate systems) and "repertory savings" (related to inputs like records, tapes, or software). They characterize the vertical linkages requiring compatibility, and show that the source of a technological change can influence how competitive markets (and dominant firms) coalesce around (or resist) particular standards. Berg (forthcoming) derives the conditions for optimal standards in the context of the theory of public goods. Market augmentation is viewed as the main source of compatibility gains.

Clearly the shift away from regulatory mandates of technical standards has implications for new telecommunications services. With the AT&T divestiture, a major new player has entered the competitive arena and seven regional holding companies are beginning to explore the implications of new technologies for regulated local operations and for their unregulated subsidiaries. What once seemed to be an integrated industry has become three separate markets: customer premises equipment (CPE), local exchange transport, and interchange transport.

Dorros (1985) argues that interface standards and performance standards are essential for proper functioning of the telecommunications subindustries. The former define how equipment in the submarkets can be linked in terms of technical protocols (signal levels and channel structure), while the latter refer to how one allocates, say, maximum decibel loss, to subindustries so desired end-to-end performance is maintained. He is concerned that bilateral ad hoc standards may raise costs or even lead to market failure. Dorros is less concerned about network architecture standards (switching hierarchies or routing algorithms), equipment standards (for compatibility within a subindustry) and service standards (signal to noise ratios or bandwidth), yet a case can be made that inefficiencies can arise for these areas as well.

Policy makers need to obtain empirical evidence on how the cost of network reconfiguration is affected by various levels of standardization. Furthermore, the distributional impacts of these costs are not unimportant from the standpoint of policy development. In partial recognition that the glue is gone, the regional operating companies have formed the Exchange Carriers Standards Association. While such organizations may promote network compatibility, they potentially could limit competition--by excluding potential suppliers or limiting interfaces with competitive technologies.

As is noted in the final staff report of the Federal Trade Commission on Standards and Certification (April 1983),

> [Standards and certification] can produce significant societal benefits by aiding information flow, hastening technology transfer, and promoting efficiencies in production and distribution. Standards... are developed through organizations which bring together committees of persons knowledgeable in discrete product areas... [They] often form the basis for buyer-seller transactions in complex goods. (p.12)

The FTC's main concerns were with anticompetitive impacts of excluding products, imposing unnecessary technical restrictions, diverting business from one producer to another, and hurting consumers. Most of the cases cited in the FTC study referred to non-technology-intensive products, where some form of certification was important to assess the market. But the FTC recognizes that many products are parts of complex systems, where the value of the basic equipment and associated inputs or attachments depends on compatibility among the components. In some cases, as with phonographs that can play records of 78, 45, or 33 1/3 rpm, the cost to handle several standards may be small. However, the coexistence of multiple standards often raises questions as to which formats will dominate the market in the future, as in the videocassette and videodisk industries. If some benefits to interchangeability are external to the individual firm, underprovision of compatibility may result.

Recent models have examined the consequences of rivalry, cooperation, and government mandated standards. If the private gains to collective action are substantial, some cooperative standards activity will result (despite spillovers). Not only are the costs of meetings relatively small, but gains occur in many areas, including market augmentation (if compatibility results), reduced input costs, and improved understanding of underlying nonproprietary technologies. Nelson (1982) and Bozeman et al. (1986) have stressed the last point by noting that firms have incentives for sharing information related to basic research. Of course, strategic considerations can delay standards development, especially if the basic technology is not stabilized and firms perceive different market potential for compatible products. Finally, antitrust concerns arise when cooperation pervades the industry.

Any model of the standards specification process needs to be able to accommodate the points raised in the case studies. For example, Brock's (1975) work on COBOL and codes for information interchange yielded two hypotheses:

(1) Self-regulation [cooperation] is more likely to occur in situations where the regulations do not upset the competitive relationship among firms.

(2) Self-regulation is more likely to occur if firms are somewhat balanced in size, causing the regulations to affect each firm equally.

Brock concluded that the computer industry differed from others which had successful experience with self regulation. Product certification programs and safety regulations have tended to affect the perceptions of consumers towards the products of some industries as a whole. Thus, there are gains to all from cooperation (as the market expands). However, gateway technologies and compatibility standards for computers often affect the relationships among companies. Incentives to cooperate are dampened if firms perceive a zero-sum game. Furthermore, with IBM the dominant mainframe and micro producer, its standards tend to become *de facto* standards, which further reduces IBM's incentives to cooperate in the development of voluntary standards (since early disclosure would reduce IBM's lead times).

Hunt (1975) in his study of major appliances, developed additional hypotheses:

> (3) Self-regulation is more likely to occur where it can help improve industry sales and margins and/or where profit-reducing government regulation is believed to be probable if self-regulation is not undertaken.
>
> (4) The existence and power of an independent organization which can carry out the self regulation programs is positively related to the likelihood that such a program will develop. Further, the importance of such a staff increases as the number of participating firms and the number of policies under consideration increase, since these two factors affect decision-making costs. (Hunt, 1975, pp. 52-53.)

The threat of government action was important for home appliances, since safety and certification were the main factors inviting government intervention. On the other hand, while the National Bureau of Standards was outraged in 1969 by the introduction of the IBM System 3 (which was neither ASCII nor EBCDIC), apparently no other government agencies put pressure on IBM through procurement policies. Given the technological opportunities in computers, the perceived likelihood of "outside" intervention was probably low, leading to less concern for this factor.

Note that cost interdependencies can reinforce the demand augmentation gains from standardization. The literature on integrated circuits is replete with references to cost-savings as the major motivation behind the cooperative development of information protocols (or the acceptance of standards set by innovators). For example, Rosenberg and Steinmueller (1982) state, "[Integrated circuit] firms have been compelled to standardize designs and to agree on industry standards of connection and communications." They argue that multiple supply sources bring lower prices. Perhaps most important, with standards specified, systems designers can incorporate the component into the product even before delivery. They also point out that the exchange of electronic signals requires successful linkages between components produced by different subcontractors. Rosenberg and Steinmueller conclude, "Standardization and connection standards may seem purely technical details to the casual observer, but in fact they reflect the importance of achieving economics of scale." (p. 183)

Other economists have also stressed the role of standards in the industry:

> Accompanying the rapid pace of innovation in the integrated-circuit industry has been an intense competitiveness among firms. With each new round of product development, several firms typically vie to have their product design accepted by customers as the industry standard. As soon as a clear favorite emerges, a number of additional firms enter the race and adopt the standard design. Through price competition, the introduction of improvements on the standard design, and use of marketing and distribution strengths, these firms strive for a share of sales in the new product area. (Wilson et al., 1980, p. 77.)

Soma (1976, p. 147) also accepts the view of Wilson et al., that standardization is required to attain economies of scale associated with input/output (communication signals), hardware (common communication linkages and paths), and software (languages and programs). Also, some buyers refuse to purchase chip designs made by only a single vendor since it makes them vulnerable to dislocations caused by a strike, fire, or business failure. Thus, cross licensing and imitation are widespread in the microelectronics industry.[7]

IV. Concluding Remarks

The fundamental question is whether too much or too little is being done to promote compatibility and innovation in telecommunications. Suppliers and buyers each have incentives to take some initiative in the establishment of standards. Standards specification by producers opens up the possibility of foreclosing the market to potential entrants, especially if the standards prove to be unduly restrictive or dependent upon special patented procedures. Thus, the main FTC recommendation for standards organizations involved improved procedural practices so all affected parties could have their complaints and concerns addressed in a balanced and timely fashion.

Similar concerns arise if buyers cooperate in the specification of standards. Specification of performance criteria by buyers is, in effect, a form of market demand aggregation. Where previously there were a large number of diverse needs, a single market emerges. At issue is whether a particular buyer or producer is excluded without there being significant social benefits.

Whoever takes the initiative, the advantages are clear for potential producers and users of the product. For manufacturers, information-gathering cost are reduced, and the expected extent of the market demand is larger--thus reducing commercial risk. In the process of specifying functional characteristics of the product, prototypes may be developed under contract to potential producers, which results in a sharing of technical risks.

Of course, supplier and user associations are not the only groups capable of defining product standards. For particular industries, the role of the federal government in establishing *de facto* guidelines can be significant. As the single largest purchaser of many inputs for defense, for example, it can help define the acceptable characteristics of new inputs. Nevertheless, the losses from premature standardization could be substantial. This concern is presumably at the core of recent FCC decisions.

Beyond the traditional antitrust problems (which may not be great if adequate institutional precautions are taken), there is a fundamental problem with cooperative specification of standards, whether by producers or consumers. Even functional (rather than physical) standards almost always exclude (or delay) some technology from competing in the future; however, without standards specifications, no market may exist.

Thus, an element of technological forecasting is involved in the selection procedure; firms with vested interests in particular approaches may frustrate the selection of efficient guidelines. For example, Motorola is the dominant producer of land mobile radios. It has fought changes in FCC rules which would permit the introduction of new technologies. In addition, potentially fruitful avenues of research may be closed off by premature rigidification; potential entrants in the input-supply industry may be locked out of the competitive process. However, self-regulated standardization or certification programs may also be defended on the basis of economy gained through interchangeability and a reduction in entry barriers (through lower design costs). A "rule of reason" approach suggests that some limits on group action be imposed. Furthermore, agreements for the "free sharing of advances" may introduce disincentives to innovative activity since participants have lower incentives to "be first."

Although standards have emerged from complex input-output relationships in many industries, most of the examples used here arise in the context of information processing. Yet the historical example of railroad gauges best illustrates how compatibility problems arise and can impose costs on individual demanders and on suppliers. In Britain, being first with railroads involved some economic gains, but retention of multiple gauges may have been quite costly. The source of incompatibility is understandable: a firm tunneling through a mountain wanted narrow gauges, while another preferred wider gauges, in the pursuit of a more even ride. Decades later, after heavy investments in incompatible networks, shipments were still being unloaded from one train and reloaded onto another. Possibly, if modularity among containers had been more extensive, the efficiency consequences would have been minimal.

Today, electric pulses signaling 0's and 1's may be *so flexible* that *standardization* is unnecessary in many cases. However, standards *specification* may still require cooperation for defining families (layers) of protocols which best facilitate the subsequent development of gateway technologies. Thus, the cost of "transhipment" (via specialized chips) may be small even if production runs are low. Due to the nature of the underlying technology and to demand characteristics, this process seems to be occurring in videotex, computers, and networks without substantial coercion.

The issues described here are not going to be easily resolved, even analytically, let alone institutionally. However, given the implications of standardization for competition, innovation, and international trade, most would agree that the standards problem is one the most important, yet understudied, issues before us today.

Endnotes

1. Besides innovations in computers, these developments include direct broadcast satellites, point to point microwave, two-way cable systems, low power television, teletext and videotext, narrowband land mobile radio, and cellular radio.

2. Standards serve a number of functions, including variety-reduction, information, quality, and compatibility (Link 1983, Link and Tassey 1987). Variety reduction standards limit the range of product characteristics, facilitating comparison shopping and allowing suppliers to achieve scale economies. Information standards included test and measurement methods for quantifying attributes of new technologies or products (Tassey, 1982). Quality standards, such as the UL listings for electric appliances, set levels of product performance, including safety, reliability, and durability. Compatibility standards, which is the main topic of this paper, specify properties necessary for a product to be used with a complementary product or in an interdependent system.

3. See Hinden (1982) for an overview of technological developments and Neustadt (1982) for a comparison of proposed standards.

4. As Witten (1983) describes it, RS-232C has four parts: "electrical signal characteristics (voltages and interpretations as 0's and 1's), interface mechanical characteristics (plug size), functional description of signals (21 in number), and a list of standard subsets of signals for specific interface types."

5. Incompatibilities (and lack of modularity) can be designed into systems to insulate a product from rivals. Such a strategy can be fatal for a fringe producer. One reason given for Texas Instruments dropping out of the home microcomputer market was its failure to adopt industry standards. The TI machine used a patented feature in its own cartridges, so that third-party suppliers were discouraged from developing software. This strategic decision may have been fatal.

6. On the other hand, in a letter to the author, Irwin Dorros states: "The carriers' interests in ISDN standards stem from their strong desire to interface effectively with their customers in this era of divided responsibility for end-to-end service. Be assured that the carriers' differences with the FCC on the location of the interface is not based on their desire to move "enhanced services back in the network", despite assertions by some. There is little economic incentive to do so. The carriers are interested in a *practical* interface with maximum decoupling of the network from CPE (Customer Premises Equipment). The carriers believe this will stimulate the most innovative, timely, and the least cost deployment of ISDN. Further, it will ensure the benefits of ISDN to all telecommunications customers, large and small alike. Unfortunately, the FCC has viewed the matter as an equipment supply issue rather than an interface standards issue."

7. Rodgers (1981) describes information-exchange in Silicon Valley, as it relates to the development of our technologies. G.M.P. Swann (1987) analyzes the rapid growth in second-source activity in microprocessors. He views network externalities as an important feature of this market: limiting incentives for new design entry but enabling new entry by firms. For a fascinating characterization of similar issues in the early automobile industry, see Thompson (1954). He explored the linkages between mechanical technology and business structure, as he emphasized the role of the Society of Automative Engineers in

developing interchangeability standards. As would be expected, smaller companies were the main supporters of intercompany technical standardization. In a more recent example, Link and Tassey (1987) examine numerically controlled machine tools in automated batch manufacturing.

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