8

Advances in Network Technology

MARVIN A. SIRBU, JR.

BRUCE C. N. GREENWALD

DALE N. HATFIELD

A. DANIEL KELLEY

Marvin A. Sirbu, Jr.

A vast army of researchers in dozens of companies continues steadily to advance the state of the art in telecommunications across a broad front. Thus, it would be presumptuous to attempt to review all of the developments in telecommunications technology that have occurred since divestiture. My objective is something at once more narrow, and more speculative. I will consider the question of how the evolution of technology since 1984 would have differed had there not been a divestiture.

I formulate the question in this way for several reasons. First, it would be misleading to attribute the new technologies which have appeared since 1984 to divestiture. This is the post hoc ergo propter hoc fallacy. In evaluating the breakup of AT&T it is important that we not attribute too much to it. Virtually all of the technologies implemented since 1984 were being actively pursued in industry research

laboratories prior to divestiture. Thus, divestiture has primarily affected the rate at which existing technologies have been deployed, and to a much lesser extent it has created incentives for the development of new or different technologies. Of course, we know from the theory of the learning curve that changes in volume lead to numerous incremental, but cumulatively important, changes in technology; in this sense, faster deployment has led to technological change as well. Similarly, major new research stimulated by and undertaken since divestiture takes more than these last six years to be deployed.

Moreover, divestiture is only one of many changes in public policy over the last decade; certain decisions by the FCC, such as *Computer III*,[1] have had as much or more impact on technology than the MFJ.[2] Furthermore, I would argue that *Computer III* was not just itself a response to the MFJ; it would have been needed in light of the inherent weaknesses in *Computer II*,[3] with or without divestiture.

Finally, by formulating the question in this way, I hope to reduce the problem to manageable proportions by focusing on how the technologies deployed since divestiture are different than what might have been had there not been an MFJ. However, while narrowing the scope, this device also makes our task somewhat more speculative, for I now have a counterfactual: how do I know what would have happened even without divestiture?

The antitrust complaint against AT&T charged the company not only with monopolizing the interexchange market, but also with impeding competition in the supply of network equipment. Several of the most significant impacts of the MFJ follow from the separation of Western Electric, AT&T's manufacturing arm, from the RBOCs, and the consequent change in incentives for both AT&T and the operating companies.

The market for customer premises equipment in the United States was fully competitive prior to the consent decree as a result of the *Carterfone* decision of 1968[4] and the registration decision of 1976.[5] In this environment, competitors attacked AT&T's market for PBXs and the central-office-based, functionally equivalent Centrex service. As noted by Walter Bolter and James McConnaughey in the previous chapter of this volume, for a variety of reasons AT&T adopted the strategy of trying to migrate users from Centrex to PBXs. Beginning in the late 1970s, it stopped enhancing the functionality of Centrex, and through various pricing policies encouraged Centrex users to buy a PBX. By 1984, the market for Centrex stood at 8.3 million lines, while the installed base of PBXs totaled 21 million stations.[6]

After the announcement of the consent decree, the incentives of the

RBOCs and AT&T were no longer the same. While the RBOCs could sell and service CPE, they were prohibited from engaging in manufacturing; AT&T retained all manufacturing operations. As a consequence, many of the RBOCs concluded that they had more to gain from selling and servicing Centrex than from selling PBXs. For some, such as Bell Atlantic, defending Centrex was critical: more than 52 percent of the business lines in Washington, D.C. were Centrex lines; the loss of this business to PBXs would strand millions of dollars of undepreciated investments.

At the time divestiture was announced in 1982, PBXs had the advantage over Centrex in four major areas: call signaling features, management features, networking capabilities, and data. In each of these areas, as a result of pressures put on them by the RBOCs, the switch manufacturers have upgraded their products in order to make them more competitive. Let us look at each area in turn.

The introduction of stored program control switches—such as the Rolm CBX or the #1ESS central office switch—means that it is possible to introduce many new features for the convenience of users just by altering the software. Services such as call forwarding and speed dialing were the first. By the early 1980s, however, the number of such features that might be ordered with a PBX had reached into the hundreds: "camp-on-busy," variable and fixed call forwarding, remote call pickup, and many more. Centrex lagged far behind in the number of such features typically available. Much of this gap has been made up in the years since divestiture.

In the management area, PBXs were providing reams of detail on telephone usage—station message detail recording (SMDR)—to aid in accounting and system management, while Centrex continued until after divestiture to provide only toll records, and often not in easily manipulable form. In 1982, reassigning a telephone number to a new room for a Centrex user might have required a written purchase order to the telco, two weeks, and a service charge of up to $100. By contrast, most PBXs provided the corporate telecommunication manager with a terminal from which he could reassign numbers instantly with a few keystrokes. Beginning in 1985, the RBOCs began offering customer controlled reconfiguration (CCR) capabilities which offered similar control.

Elsewhere in this volume is mentioned the history of the "subsidy" which flowed for many years from long-distance service to the BOCs. Prior to divestiture, a large user could escape this tax on switched toll services (MTS) by configuring a network of leased lines between com-

pany locations, and routing intracompany traffic on its "private network." The federal government, with its FTS (Federal Telecommunications System) network was and continues to be the largest operator of such a private network, and has saved billions of dollars in the process. For obvious reasons, the BOCs were slow to equip Centrex to manage such networks, thereby providing further incentive to users to switch to PBXs. The repricing of switched long-distance since divestiture has reduced somewhat the advantages of leased-line networks, diminishing this motivation for switching. But more importantly, in response to customer demand, the RBOCs have required from the switch vendors improvements in the capabilities of Centrex in this area. Thus, we have seen a wide range of feature enhancements to Centrex, which I believe can be directly traced to the new incentives created by divestiture. The result has been a compound growth rate for Centrex of 6.8 percent from 1984–1989, while the installed base of PBX lines peaked at 2.6 million in 1988 and is projected to decline 4 percent by 1990.[7]

We turn next to the area of data capabilities. Rolm was the first, in 1976, to introduce a PBX that used digital rather than analog techniques to switch calls. Rolm touted its product as eventually making it easier to use the PBX for switching data as well as voice within the firm. AT&T had delayed developing central offices based on digital switching, correctly arguing that they would be uneconomic compared to dedicated data switching systems such as port switches or local area networks. Unfortunately, in a classic example of selling the sizzle not the steak, Rolm and other PBX vendors successfully sold hundreds of digital PBXs because of their data potential, which was seldom utilized in practice.

For the BOCs, the only solution was to convert as rapidly as possible to digital central office switches that could offer comparable capabilities. The rapidity of conversion to digital central office switches by the RBOCs is, I believe, another major consequence of divestiture. It is a result of the confluence of several forces originating with divestiture, not merely the need for a digital Centrex capable of competing with digital PBXs. As a result of the MFJ, the RBOCs were faced with massive capital investments to meet the access requirements. In many cases, they concluded that it would be cheaper to simply accelerate the replacement of outdated step-by-step and crossbar central offices with new digital switches, rather than invest in costly adjuncts or access tandems. Moreover, as noted in more detail below, the rapid increase in the use of digital fiber optic transmission capability, itself a result of divestiture, also made digital switching more attractive. Terminating a

digital transmission link on an analog switch requires costly channel banks, whereas with a digital switch less expensive digital interfaces are required.

Of course, digital switching would have been phased in even without divestiture. By 1983, Western Electric had already spent more than one billion dollars developing the #5ESS digital central office switch. The continuing decline in digital logic costs, which has produced dramatic improvements in price versus performance in the computer industry, has similarly affected telecommunications switching. However, the RBOCs went from a negligible fraction of their lines terminating on digital switches on January 1, 1984[8] to more than 36 percent by 1989. This rapid rate must be attributed in part to divestiture.[9]

At the same time, the RBOCs' switch market has shifted from a virtual monopoly with AT&T, to a duopoly, with Northern Telecom and AT&T splitting over 90 percent of the sales. Half a dozen U.S. and foreign firms split the remainder, with no vendor yet showing clear signs of emerging as the RBOCs' third major supplier. The competition for these digital switch sales has been extremely intense, with switch prices dropping from $400–500 per line to $100–200 per line. In part, this represents a "give away the razor, sell the blades" strategy; the initial capital cost of a switch is only a small fraction of what a vendor expects to receive eventually from the BOC. Additional line cards, new software releases, maintenance contracts, and other continuing revenue sources provide the bulk of the profits. Once a totally new switch is put in place, it generally stays in place for twenty to forty years while virtually all of its components are swapped for newer printed circuit boards, thus ensuring that the initial sale locks in a substantial future revenue stream. It is unlikely Northern Telecom would have succeeded in wresting half of the market away for Western Electric had divestiture come seven or eight years later, when most of the digital switch commitments would have already been made.

While the move from monopoly to duopoly has surely driven down switch costs, it has raised new issues of compatibility and standardization. For example, the manner in which Northern Telecom switches were designed, to provide 56 kbps. service, was different from the method chosen by AT&T.[10] Multiple switch designs result in increased training and adaptation costs. As a result, if one looks closely at the composition of switch sales among the seven Regionals, one generally finds each region aligning with one manufacturer. Thus, the great bulk of NYNEX's digital switch purchases have been from Northern Telecom, while Bell Atlantic seems to prefer AT&T.[11]

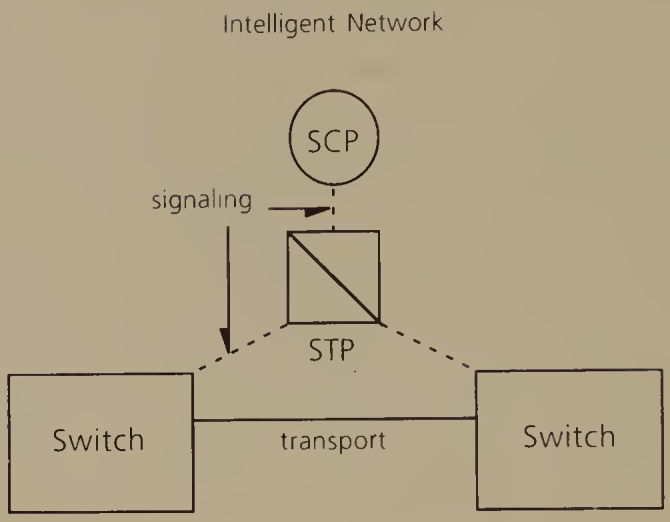
With the introduction of stored program control switching in the

1960s, the telephone industry began a gradual shift from services implemented in hardware—e.g. electromechanical relays—to services implemented in software. As suggested by the discussion of Centrex above, there are hundreds of new features and services which customers are demanding from their telecommunications system that software can readily provide. With the current generation of technology, the BOCs are dependent upon the central office switch manufacturers for the implementation of new software-based services. Thus, in order to offer a service like "camp-on-busy" the carrier must request that the switch vendor provide a new software release for the central office incorporating such a service. As the basis for competition in telecommunications became increasingly dependent on the rapid implementation of software-based services, the BOCs found themselves intolerably dependent upon the responsiveness of the switch manufacturers. Moreover, the MFJ prohibited the normal business response of integrating backwards into switch manufacture. As an alternative, the BOCs began work in 1985 on a new model for how switching and software-based services ought to be provided in the network of the future, which has been called the "Intelligent Network."

In today's network, virtually all the software, which determines the services offered by the network, runs in the central office switches. Because the switches must respond in real time to hundreds of thousands of requests for service per hour, switching system software is incredibly complex, expensive, and almost completely controlled by switch vendors. In the Intelligent Network model, the switch is seen as a highly intelligent server, responding to instructions from an attached processor. The distinction is much like that governing the separation of window managers from application programs in the computer world: machine vendors are responsible for providing an operating system that provides simple command primitives for controlling the computer display; the application programmer then calls on these window management primitives—e.g., open a window, draw a line, shade a polygon, etc.—to produce complex pictures through repeated use of these primitive operations. Indeed, in modern distributed computer systems, the application program might run on a completely different machine than the window manager. By separating the display functions into client and server layers, applications can be quickly developed by third parties without having to make changes in the complex, hardware-specific server software.

In much the same manner, in the Intelligent Network model, the vendor's switch would be capable of executing numerous primitive operations—collect the number dialed, complete a circuit between two

FIGURE 8.1



numbers, etc. The application programs that link together these primitives to provide sophisticated services would reside on separate machines, programmed by the BOCs themselves and communicating with the switch via digital communications protocols such as Signaling System Seven (SS7).[12]

A block diagram of such a system is shown in figure 8.1. The Service Control Point (SCP) represents the attached processor. Given the dialed digits collected by the switch, the SCP could then decide, based on the called and calling number, the time of day, or any other criteria which had been programmed, exactly how to route the call. AT&T is already using a very similar model for providing advanced 800 Services and Software Defined Network.

The Intelligent Network concept is an inevitable response to the demand for more rapid introduction of new and customized call handling services. It is an extension to telecommunications of the same model of layering of software functionality that we are seeing in the corporate world, with back-end databases responding to standardized queries from numerous different applications generated by MIS (Management Information Systems) departments and end users.[13]

Moreover, with the Intelligent Network model, the carrier is no longer totally dependent upon the switch supplier for providing new services because the SCP is under the carrier's control. The local exchange carrier can introduce new services more quickly and make them available throughout its network without reprogramming every central office. As the set of primitives provided by the switch vendors becomes more standardized, problems of coordinating new offerings across het-

erogeneous switches are reduced. Indeed, even if there had not been a divestiture, we would likely have seen some evolution to redistribute functionality between switches and SCPs. The same reasons of flexibility led AT&T to introduce the first systems of this type in 1979, and caused MCI and Sprint to follow suit in 1988.[14]

Ameritech first initiated the Intelligent Network concept, post-divestiture, in 1985, under the title: "Feature Node/Service Interface." In addition to facilitating service creation by the operating companies, the Intelligent Network, with attached processes able to control switches remotely, is potentially the basis for a true ONA.

The Intelligent Network represents a profound change in the architecture of the network and will not be implemented quickly. Unlike MCI and US Sprint, which are also moving their networks in this direction, many of the BOCs' switches are still electromechanical[15] and cannot be reprogrammed to support the new architecture.[16] Older SPC switches will need substantial increases in processing power, along the lines of Northern Telecom's SuperNode processing upgrade.[17] A complete transition to the Intelligent Network, like the shift from analog to digital, will take decades. In addition to the resistance of switch vendors, which can be expected as this strategy threatens their role, there are substantial technical barriers to overcome, such as ensuring that removing call processing logic to a remote processor does not introduce unacceptable call processing delays.[18] Bellcore has announced a phased schedule, with the first IN components to be specified and agreed to by 1990 and available by 1993, with other components to be defined by 1992 and available by 1995.[19] The challenge for the carriers is to find a reasonable compromise between a desire to "have it all" and the need to set targets which are realizable in a timely fashion.[20]

While some such services can be provided to the largest users by customer premises equipment (e.g., PBXs), smaller users and smaller branches of large firms typically do not have the traffic volume to justify the fixed capital expense, or the expense of providing twenty-four-hour a day maintenance at far flung locations. The shift to an Intelligent Network software architecture is an inevitable response to the growing demand from customers for more rapid introduction of new network services. That response has been accelerated, however, by the change in the relationship between local exchange carriers and switch vendors caused by the MFJ.

Integrated Services Digital Network, or ISDN, is an umbrella term that describes the long-term trend to convert the world's telecommunication networks from analog to digital. The International Consulta-

tive Committee for Telegraph and Telephone (CCITT), the world body that coordinates telecommunications standards development, first began working on ISDN in 1976. The first drafts of ISDN were completed in 1984. Thus, the move towards ISDN considerably predates divestiture. The three kcy elements of ISDN are: communications channels that are digital end-to-end; a signalling channel associated with each access line, which can be used both for signalling to the network and for end-to-end signalling between customer terminals; and the interleaving of bit streams through a standard interface for user access, in order to accommodate a broad scope of services.

Divestiture has both positively and negatively affected the rate of implementation of ISDN technology. The technology encompassed by ISDN is exactly what the carriers need to provide a digital Centrex service that can compete with digital PBXs. Following divestiture, the BOCs had to rely on independent manufacturers to supply both the central office switch and handsets and terminals needed to provide digital Centrex. The BOCs need the impetus provided by a worldwide standard to persuade both switch vendors and terminal manufacturers to produce the necessary equipment. The BOCs have thus been ardent supporters of both the ISDN concept and ISDN standardization. Unfortunately, without the power of an integrated AT&T to set standards, divestiture can probably be blamed for a two-year delay in the development of standards for the ISDN CPE interface with the network.[21]

At divestiture, AT&T Communications was granted the existing CCS network. The BOCs had to start from scratch to develop their own CCS systems, which has also served to delay the introduction of ISDN services. On the other hand, the BOCs have had strong incentives besides ISDN for proceeding with CCS deployment, such as the lucrative 800-number services market. The greater the success of the competitive carriers as a result of divestiture, the greater the value of a BOC CCS-based capability for providing 800-number service.

One consequence of the divestiture was to create seven RHCs for the BOCs where before there had been one. This regionalization has affected technology development in several ways, and may have even morc profound effects in the future.

The differences in the territories served by the RHCs have led to differential emphasis on technologies. Where in the past AT&T may have forced all of the BOCs to adopt a common approach, divestiture has made divergence easier. We have already addressed regional divergence in the selection of switch supplier. The average number of lines per switch in the predominantly rural US West region is half the number in the more urbanized Ameritech region.[22] This leads to a difference

in the distribution of switch technology and the preferred suppliers.

The regions are also competing head-to-head in cellular mobile telephone service; many of the "non-wire" licenses have been bought by out-of-region RBOCs. If one examines the new R&D laboratories set up outside the framework of the commonly-owned Bellcore, one finds, at NYNEX for example, a significant effort in cellular telephony research.

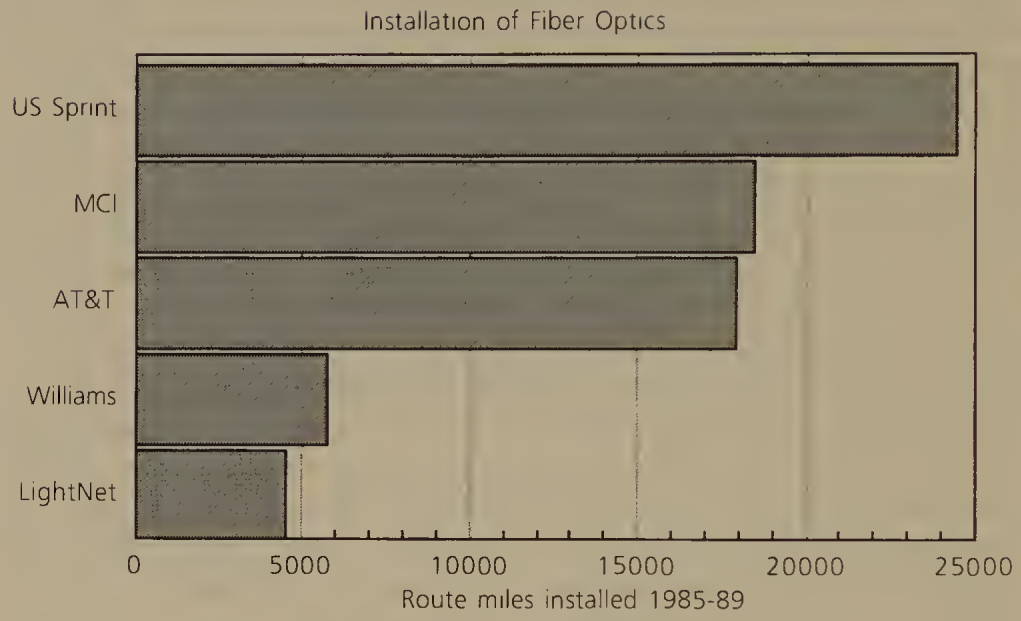
In April 1989, Pacific Telesis became the first BOC to acquire a cable television operation outside its franchise area.[23] To date, cable television operators have generally shied away from implementing the technologies that would allow them to compete head-to-head with the telephone companies in the provision of voice and data services. As telephone companies acquire cable systems, perhaps this will change. Under the current FCC Cable/Telco cross-ownership rules (which are themselves up for discussion), a local exchange carrier cannot own a cable television operator within its service area. When AT&T was integrated, this rule eliminated 80 percent of the country, and most major markets. With regionalization as a result of divestiture, the situation has changed dramatically.

Divestiture has clearly stimulated competition in the interexchange market. AT&T's share of interstate switched traffic, in minutes, went from 80.0 percent at the end of 1984 to 71.2 percent by the third quarter of 1987 and 66.8 percent in the first quarter of 1989.[24] Much of the improvement in market share came about as a result of the implementation of equal access and the associated balloting process.[25]

In order to service the growth in traffic expected as a result of equal access, the competitive carriers such as MCI and US Sprint were obliged to make massive investments to increase capacity in their networks; and the technology of choice as clearly optical fiber. In the period 1985–1989, US Sprint installed 24,000 route miles of fiber, MCI 18,000 miles, and AT&T 17,500 with typically 10-32 fibers per route mile, or more than 1.5 million miles of fiber (figure 8.2).[26] Operating at data rates as high as 1.7 Gbps., a single pair of optical fibers can carry more than 25,000 voice conversations simultaneously! If each of the fibers were equipped with the electronics to run at these rates—which they are not—it would amount to more than a factor of three increase in interstate network capacity since divestiture.

There have been substantial improvements in the technology of optical fiber systems a result of the massive investment in fiber. The price of optical fiber has dropped dramatically, to as low as twenty cents per meter.[27] Electro-optic components, such as lasers and detectors have been dropping in price at rates greater than 30 percent per year. The tremendous improvement in price performance has greatly

FIGURE 8.2



Source: Kessler Marketing Intelligence.

accelerated interest in fiber all the way to the home on the part of the local exchange carriers.[28] All of this is clearly a result of divestiture's impact on interexchange competition.

Along with equal access came equal access charges and a reduction in the price difference between AT&T and its competitors. Competition for large customers has shifted from price to service with both AT&T and its competitors introducing customized offerings for large businesses and various forms of virtual private networks. The growth in these software-based services is another consequence of heightened interexchange competition.

The 1980s have also witnessed a dramatic growth in private networks: leased lines tied together by customer-owned tandem switches and PBXs. The growth of private networks has several causes, not all of them related to divestiture. The policy of taxing switched toll service usage to pay for non-traffic-sensitive local plant provided a large financial incentive to escape the tax through the use of leased lines for over fifty years. Had subscriber line access charges been phased in more rapidly—a decision in the hands of the FCC and Congress, not Judge Greene—the growth of private line networks would likely have been significantly less. Competition in CPE led to the availability of end-user equipment capable of switching and managing large private net-

works, thus facilitating their growth. To some extent, the confusion created by divestiture led many companies to think about creating their own private networks as a way to reduce their dependence on the suddenly fragmented carrier industry.

To discourage investments in local bypass transmission technologies by their customers, virtually all of the BOCs greatly accelerated their investments in local interoffice and feeder fiber capacity. They also hoped to preclude a wave of intraLATA competitors who were freed to enter the marketplace by the more relaxed entry policies adopted by some states following divestiture.

The proliferation and variety of CPE, ranging from residential handsets and telephone answering machines to corporate PBXs and voice mail systems, is often attributed to divestiture. Such a view is not supported by the facts. *Carterfone* preceded the MFJ by fourteen years. As a result of the registration decision and *Computer Inquiry II*, the marketplace for CPE had become fully competitive before divestiture. By 1985, AT&T's share of the PBX market had dropped to 25 percent. If divestiture impacted the technology of CPE, it was to require PBX manufacturers to incorporate much more sophisticated call routing capabilities in order to deal with multiple carriers and bypass.

Finally, we should consider what impact the MFJ's ban on BOC and AT&T involvement in information services has had on technology development. The BOCs have not hesitated to call attention to widespread use of videotex services in France and bemoan the restrictions on their participation embodied in the MFJ. Here it is worth returning to our counterfactual: what would have been the situation in the absence of divestiture? Prior to the divestiture, the Senate had already passed legislation incorporating a ban on AT&T's participation in electronic publishing. *Computer Inquiry II* had established strict structural separation between a carrier's basic and enhanced services operations. Finally, prior to divestiture, while still an integrated company, AT&T's videotex venture, its viewtron system, failed miserably. Thus, for reasons relating to both policy and the marketplace, it is not clear we would have witnessed any golden age of information services if only the MFJ had not restricted BOC participation.

Moreover, even with relief from the FCC's structural separation requirements granted in the FCC's ill-fated *Computer III* decision, as well as with Judge Greene's relaxation of the MFJ requirements regarding information storage, processing and protocol conversion, it is not certain that the BOCs would find the right technical and marketing strategy to make a success of the information services business.[29]

With respect to the manufacturing restrictions imposed by the MFJ,

there has probably been a modest technological effect. The BOCs are in a position, as users of telecommunications technology, to recognize potential for new hardware and software to meet customer needs. However, to the extent that this recognition requires elaboration through applied research and development, the BOCs are not in a good position to appropriate all of the benefits of that research and development, except through arms-length royalty arrangements with manufacturers. Not all know-how is easily protectable and transferrable in this manner. While the existence of Bellcore provides a partial means of reducing the cost to any one firm of generically relevant research, it still does not allow the RBOCs to readily appropriate benefits that may be derived outside the local exchange industry. At the same time, the restrictions on manufacturing have had a substantial positive influence on standardization. Without proprietary interest in any particular technology, the RBOCs, through their agent, Bellcore, have been the most fervent proponents in the U.S. telecommunications industry of compatibility standards.

If we examine the rate and direction of technological change since divestiture, we can draw several interesting conclusions. First, changes in industry structure change the incentives for developing specific technologies. Second, competition spurs investment, which in turn, through learning curve effects, spurs the improvement of technology. The improvements in fiber optics are a good example. Third, where decisions on technology choice are in the hands of a single firm, investment (and hence technological change) can proceed rapidly. We have seen this with the diversity of software-based services introduced by the interexchange carriers or CPE vendors individually. However, where progress requires coordinated decisionmaking by multiple firms, as with ISDN, then increasing the number of players is likely to slow decisionmaking and hence technology deployment.

Bruce C. N. Greenwald

There are many things to commend in Marvin Sirbu's analysis. In setting the question as one of assessing the difference between a world with and without divestiture, he has pointed the inquiry in a valuable direction. He has made a valuable distinction by separating the technology question into one of technology development, where divestiture has had little or no detectable impact, and technology deployment, where the effects of divestiture are more readily discernable. He makes

an important point, routinely ignored by pure technologists, that changes in industry structure, like divestiture, do affect the incentives for developing specific technologies.

However, Sirbu's specific conclusions seem to be considerably more problematical. Sirbu analyzes the effect of divestiture on nine basic technology areas: digital switching, Centrex systems, fiber optics, Intelligent Network architectures, ISDN, private network technologies, CPE, cellular, and CATV. In each of these areas, he seems to overestimate significantly the impact of divestiture on technology, even in cases such as CPE development, where he recognizes the effect of divestiture has been marginal.

In digital switch technology, Sirbu claims divestiture has had several important impacts. The equal access requirements of the consent decree have accelerated electromechanical switch replacement, speeding the diffusion of digital switch technology. Increased post-divestiture competition among switch manufacturers has reduced switch costs leading to more rapid deployment. Greater diversity among the RBOCs in terms of switch requirements (than in the old AT&T) has encouraged diversity in digital switch development. In none of these areas is the factual support for Sirbu's case strong.

While it is true that digital switch penetration among the RBOCs rose from a negligible level in 1983 to roughly 30 percent in 1988, the rate of installation of digital switches among the independent telcos during this period had been equally or considerably more rapid.[30] Also, although switch costs have declined by a factor of roughly three since divestiture, the prices of comparable pieces of computer equipment (e.g., one Mip machines) declined by fourfold or more.[31] Finally, whatever the diversity of demand by the RBOCs, the two major switch suppliers offer comparable general lines of switches whose broad outlines (and modular natures) were determined well in advance of divestiture. Moreover, the actual technology embodied in the current generation of digital switches was, as Sirbu concedes, developed well before and independently of divestiture. Thus, it is not at all certain that divestiture has had any significant impact on digital switch technology.

The one particular area in which Sirbu identifies a substantial impact on switch technology is in the development of Centrex software. In this case, the devotion of substantial effort by switch manufacturers is undeniable. However, it is not clear how far these development expenditures have affected the switch technology actually in use. Centrex, which according to Sirbu served approximately 30 percent of business lines in 1984, has continued to decline in market share, significant development expenditures notwithstanding. Centrex now rou-

tinely accounts for 3 percent or less of RBOC revenues. The fundamental economic advantages of CPE appear to have overwhelmed divestiture-induced investments in new Centrex technology.[32] Again, therefore, the impact of divestiture on technology, even in this area of particular interest, has been marginal at best.

In fiber optics, Sirbu notes that competition among MCI, US Sprint, and AT&T has lead to greatly increased fiber installation and a consequent reduction in fiber-optic costs as the industry moves down its learning curve. However, it is not clear whether fiber installation is due largely to competition engendered by divestiture. For many years, beginning before divestiture, local exchange carriers were using fiber optic cable as the medium of choice for interoffice trunks and feeder cable, even in areas where competition was not a serious consideration. But the extra fiber demand occasioned by the creation of competitive networks may have had only a minor impact on fiber optic systems cost. The United States market for fiber is embedded in both a global market for fiber, and a broader market for optical-electronic devices (the major current costs of fiber consist of system and termination electronics). The addition of long-distance fiber miles by MCI and US Sprint represents only a relatively marginal contribution to this worldwide and industry-wide enterprise. Except in the specific area of long-distance fiber systems, the effects noted by Sirbu are likely to be small. In terms of changing telecommunications technology, it is the economics of fiber loops to the home, not these long-distance loops that are critical.

The impact of divestiture on implementation of ISDN is, as Sirbu himself concludes, ambiguous. The RBOCs' demand for digital Centrex has, he reasons, fueled the demand for ISDN (although it may have distorted the direction of ISDN development). On the other hand, the difficulty of obtaining agreement on ISDN standards may have delayed ISDN introductions. Neither factor appears to be critical to ISDN implementation. The chief physical (and cost) components of ISDN are digital switches, already discussed above, and end-office SS7 capability. The RBOCs are now beginning to install SS7 for reasons unaffected by divestiture—chiefly the demand for enhanced calling services by households and internal telco management capabilities. The other principal component of ISDN, terminal electronics and switch interfaces, can be installed on a demand basis. Thus, the impacts of divestiture on ISDN development have not only been offsetting, but may have been marginal at most.[33]

In the area of Intelligent Network architecture, Sirbu maintains divestiture (and, in particular, the separation of switch manufacture from the local exchange carriers) has accelerated Intelligent Network

development. However, he concedes that the basic concepts involved significantly predate divestiture, that currently available realizations (e.g., 800 Service) were available before divestiture, and that the architectures involved largely mirror parallel architectures in the broader area of data processing. The acceleration claimed by Sirbu must, therefore, relate to the development and deployment of more advanced forms of intelligence. Since no such developments or deployments have yet taken place, this must be almost entirely a matter of conjecture.

Moreover, it is not clear the kind of intelligence that Sirbu envisions will ever be a significant part of the basic central telephone network. In data processing, the dominant technological trend has been toward decentralization. The use of centralized facilities has greatly diminished with the development of personal computers and specialized devices (such as file-services, printers, etc.) designed to work with networks of such personal computers. Service bureaus that merely rent basic data processing capabilities of various sorts are rapidly disappearing. The reasons for this trend appear to apply equally to highly developed telecommunications network intelligence. CPE-based systems have the special advantage of being able to restrict both the user options and the kinds and generations of equipment they will accommodate. Consequently, the systems are inexpensive to develop and easy to adapt to new technology, compared to a public network which must, by its very nature, accommodate many kinds of users and many generations and types of equipment. Consider, for example, the difficulty of adapting the current telephone infrastructure of electromechanical, analog electronic and digital switches to provide ubiquitous ISDN. Those, like Sirbu, who doubt the power of this CPE advantage need only look to the expensive failure of NET 1000, AT&T's attempt to provide network-based data processing capabilities.

Sirbu's contention that divestiture has encouraged private network development rests on the claims that the continued mispricing of long-distance services post-divestiture has encouraged private networks, and that the confusion in the public network associated with divestiture may have driven customers to develop their own private networks. The first of these points actually seems to suggest that divestiture may have inhibited, if only slightly, private network development and deployment. But the overpricing of long-distance services was more severe pre-divestiture than post-divestiture, and thus divestiture should have reduced the incentives for private bypass facilities. The second claim applies only to the two years following divestiture. As the Huber Report noted, the trend toward private networks on the part of large users is a long-standing trend that continues to accelerate, despite improve-

ments in post-divestiture telephone company service levels and the pricing of long-distance access. It is not certain, therefore, that divestiture has had any impact in this area.

Finally, in the area of CATV technology, cellular, and CPE, even Sirbu regards the impact of divestiture as minimal. In cellular, Sirbu refers only to the research efforts of some of the RBOCs (e.g., NYNEX) which are only a tiny fraction of the total global cellular industry research effort. In CPE, Sirbu notes that most of the important regulatory and industry structure changes predate divestiture. And in CATV, Sirbu properly points to the fact nothing has been done by the telephone companies either before or since divestiture, and any claims for the impact of divestiture rest on conjectured future developments. Again, therefore, the likely impact of divestiture in these technologies is negligible to nonexistent.

That basic theme appears to apply across the full range of technologies. Because telecommunications technology is developed in a global context as an intrinsic part of a broad electronics and computer industry, the effects on technology of events in the domestic United States telecommunications industry are greatly attenuated. At the same time, conditions peculiar to telecommunications (e.g., the substitution of CPE for network capabilities) have further limited the technology impact of divestiture. Thus, although in general Sirbu makes a good point when he notes the impact of industry structure on technological developments, it is not a point which applies with great force to divestiture.

Dale N. Hatfield

Prior to reading Marvin Sirbu's discussion, I prepared a very rough outline of my own relating to the changes in telecommunications technology that may have been influenced by divestiture. While Sirbu has done a much more comprehensive and thorough job of analyzing post-divestiture changes in technology, I found my own outline was basically a subset of the ideas he discusses. Indeed, I found myself in basic agreement with most of what he has written.

Before I review those areas of agreement and add some comments of my own, I should state that I am in total accord with his comments regarding the importance of other policy decisions, such as the FCC's *Computer Inquiry III* attempt. Because of the intense publicity given to divestiture and its direct impact on customers (for example, the need

to select a long-distance carrier), there has been a tendency to overemphasize its role. For instance, people often credit divestiture with producing the intensely competitive market in CPE. But as Marvin Sirbu correctly points out, it was a series of FCC proceedings (beginning with the *Carterfone* decision in 1968) that led to a competitive market in CPE prior to divestiture. Thus, I think it important to avoid the tendency to place too much blame on—or give too much credit to—divestiture when it comes to analyzing post-divestiture technological development.

My original outline listed three major areas of technology change where divestiture seemed to have played an especially important, identifiable role. The three major areas were: the resurrection of Centrex and associated services; the evolution toward an Intelligent Network in the local exchange area; and the changes in the local exchange and interexchange networks directly or indirectly attributable to the equal access provisions of the MFJ.

The first area, the resurrection of Centrex, may not be the most important technological impact of divestiture, but it certainly appears to be one of the most direct and visible. As Sirbu and others in this volume have indicated, Centrex was a dying service offering prior to divestiture. It provided little more functionality than ordinary POTS and it was not being upgraded or improved—it literally appeared to be dying from neglect. Indeed, prior to divestiture, AT&T had been employing—or was allegedly employing—its so-called "migration strategy." AT&T was widely perceived to be using its market power to force customers away from Centrex and older PBXs toward more modern PBX products.

Observers at the time ascribed various motives for the migration strategy. They speculated that it was an attempt by AT&T to shift customers from month-to-month tariffed service offerings to less competitively vulnerable, and potentially more lucrative unregulated long-term equipment contracts. They speculated it was an attempt to protect—almost preemptively—an existing customer base before interconnect competition got too strong.

However, one does not have to ascribe particular motive for the strategy. Centrex service was dying, if for no other reasons than it was not keeping up with the features and functions that were and are available on modern stored program control (SPC) or "computer-like" PBXs located on the customer's premises. AT&T controlled this situation because it was essentially the only supplier of network equipment such as CO switches to the undivested BOCs. As part of AT&T and dependent upon Western Electric for their CO switches, the BOCs had

little choice in the matter. The BOC control over the local loop also gave AT&T some influence over the situation. The relative attractiveness of Centrex services versus PBX services obviously depends upon the relative costs of Centrex lines versus PBX CO trunks.

Centrex was so widely perceived to be a declining service offering that I do not personally recall any analysis of it in the divestiture discussions to which I was privy. To the best of my recollection, it was not mentioned in the original divestiture agreement between AT&T and the DOJ. The situation quickly changed with divestiture, however, and the BOCs were able (1) to pressure their equipment vendors sufficiently to obtain more competitive features and functionality, and (2) to gain support from their regulators to offer rate stabilization and other plans making Centrex competitive with CPE. In going through my files to prepare these comments, I stumbled across an article published shortly after divestiture entitled "Centrex Rises from the Ashes," as indeed it did. It was quickly touted as the "flagship offering" of the divested BOCs and it was—and still is—strategically important to the companies. As Sirbu notes, the providers of the first point of switching to the customer—whether the interconnect vendor is a PBX on the customer's premises, the local telephone company at the CO, or the IXC at a toll office—has important marketplace advantages.

I believe the customer has generally benefited from the additional choice provided by resurrected and vastly improved Centrex offerings. The BOCs have repositioned Centrex somewhat to service smaller customers, and equipment vendors have responded to provide station and associated equipment specially designed to work with Centrex offerings. Moreover, the BOCs' initial ISDN offerings are being provided to large customers on a Centrex-like basis, so there is strong evidence that Centrex will remain an important and evolving service of the BOCs.

Since BOC-provided Centrex offerings do compete directly with PBXs offered by interconnect companies, and because the BOCs still have strong control of the local access lines required by both, there remains an incentive for the BOCs to discriminate or cross-subsidize in favor of Centrex offerings. As long as this is the case, effective regulatory oversight will be required to assure that the BOCs do not artificially manipulate customer choices between network and customer premises-provided services.

The second area of technological development which seems to have been impacted rather significantly by divestiture is the evolution of the local exchange network toward an Intelligent Network. The Intelligent Network concept essentially creates a new interface in the local ex-

change which would allow the BOCs—and perhaps even end users—to utilize a common set of basic call processing instructions or "primitives" in developing new software-based services. Speaking more broadly, the concept allows functionality to be distributed flexibly at a variety of processing/database nodes, both on and off the network.

As Sirbu points out, part of the incentive for the development of the Intelligent Network concept was for the BOCs to reduce their dependence upon network equipment vendors for the development of new and improved services. A local exchange network without Intelligent Network capabilities puts the BOCs at a competitive disadvantage compared to PBX manufacturers and interexchange carriers, especially when dealing with large customers. Hence, I agree with Sirbu's assertion that the BOCs were more or less forced to pursue the Intelligent Network concept. The additional interface within the local exchange network should lead to a more competitive network equipment market and more choices for the end user. Without divestiture, one would wonder whether AT&T would have voluntarily opened another interface to the network, facilitating competition with its own applications software development.

The Intelligent Network notion is important not only because of the competition and increased customer choices it may produce, but also because it was influential in the development of the ONA/CEI concept. In *Computer Inquiry III,* the FCC tried to relieve the BOCs of the separate subsidiary requirement for the offering of enhanced services. It wished to replace the structural separation requirements with certain nonstructural safeguards, the cornerstone of which were the ONA/CEI requirements with unbundling of their BOC networks to give enhanced service providers access to basic elements on an equal, nondiscriminatory basis. Giving the non-BOC-affiliated enhanced-service operator access to the software interface described above would both diminish the extent of the BOCs' monopoly power from control of local loops, and encourage a broader range of vendors to develop enhanced services.

Given the importance of the Intelligent Network concept to ONA, I was somewhat dismayed by Bruce Greenwald's comments that difficult implementation problems may render the concept wishful thinking. The lack of this additional network interface reduces the potential effectiveness of the ONA/CEI concept and, therefore, increases the chances of anticompetitive conduct in BOC provision of enhanced services on an unseparated basis.

The third major area of technological development directly affected by divestiture stems from the equal access provisions of the MFJ. Directly identifiable are changes in hardware, software, and network ar-

chitecture necessary to create equal access. These include such things as the changes necessary to allow the subscriber to resubscribe to any competitive carrier, and then to override the resubscription and select another carrier on a call-by-call basis. They also include changes to the switching hierarchy permitting more efficient access for smaller carriers (e.g., through the addition of access tandems).

The indirect impacts of these directly identifiable changes are, as Sirbu notes, numerous and significant. They facilitated much faster growth in interLATA competition, which in turn led to much faster conversion of the long-haul network to all-digital transmission and to the rapid deployment of fiber optic facilities. This led to the faster development of at least three major long-haul networks in addition to AT&T—MCI, US Sprint, and the independent fiber carriers. This development of alternative long-distance networks no doubt played a significant role in AT&T's recent multi-billion dollar writeoffs of existing, yet dated facilities. The rapid deployment of alternative, high-capacity fiber optic facilities, with their perceived higher quality transmission characteristics, has also played an important role in driving satellite systems out of the high density, point-to-point voice network business.

Once again, I think the general public has been well-served by this accelerated pace of technological change. One of the major concerns with divestiture was the possible negative impact on national defense caused by fragmentation of the network. But, because of the careful way the interfaces between the BOC local exchange networks and the long-haul networks have been developed, the concerns about network fragmentation have been offset in part, if not totally, by the advantages of physical diversity. There have been negative consequences such as the need to develop much more sophisticated network management tools to work in a multivendor environment. Also, as I recall, the pre-divestiture AT&T was working on passing CCS information across the local exchange/long-haul boundary. With divestiture, AT&T was to retreat to an older, less sophisticated form of per-trunk signaling in order to offer equal access on a uniform basis. In short, the overall impact of divestiture on the long-haul portion of the business has been positive, but not universally so.

The equal access provisions of the MFJ also became part of the model for ONA/CEI adopted by the FCC in *Computer III*. If the BOCs could successfully be required to offer nondiscriminatory access to the local network for all long-distance carriers, it would appear they also could be required to provide nondiscriminatory access to enhanced service providers. As mentioned above, the FCC previously adopted such a

requirement as a condition for the removal of the separate subsidiary requirement.

There are differences in the two situations, however. The BOCs are prohibited from entering the long-haul (interLATA) market by the MFJ line-of-business restrictions, and thus have little or no incentive to discriminate among the different long-distance carriers. On the other hand, they have been allowed to engage in certain enhanced services such as the provision of voice messaging services or electronic mail. In these areas, the incentives for the BOCs to discriminate in favor of their own enhanced service offerings are still present. Despite the presence of these incentives, the FCC has heavily relied upon ONA/CEI to protect against discrimination when the BOCs offer such enhanced services within the same (i.e., nonseparated) company. This suggests the need for effective efforts to police the boundary between basic and enhanced services to ensure that discrimination does not occur. This need is irrespective of the perceived success of the equal access provisions of the MFJ.

In summary, it is far too early to reach any final conclusions, though I believe divestiture has had a generally positive effect on technological change and generally has benefitted consumers. There is no evidence that pre-divestiture claims of disastrous consequences will ever become a reality. Indeed, some of the tools and approaches adopted in conjunction with the MFJ (e.g., the equal access requirements) can serve as useful models in other situations.

A. Daniel Kelley

Technological change was one of the most difficult issues facing the government as it weighed possible remedies in *U.S. v. AT&T*. The pre-divestiture Bell System raised the specter of a collapse in R&D funding, with a consequent plunge in the rate of technological change, as an antitrust defense.[34] The other side of the argument, however, is that a vertically integrated monopoly can retard innovation by competitive businesses and entrepreneurs.[35] If consumers must endure both the exercise of monopoly power and the loss of innovation, they are two-time losers.

Marvin Sirbu's wide-ranging review of post-divestiture technology issues provides a measure of comfort to those who advocated divestiture. The central teaching of Sirbu's analysis is that most trends in place prior to divestiture have continued. If anything, according to

Sirbu, the pace of technological change has increased in many areas as long-distance competitors have taken advantage of the opportunities created by divestiture to invest in new technology.

The introduction of new technology into the BOC's networks, or the introduction of old technology at lower prices, is another of the substantial and immediate benefits of divestiture mentioned by Sirbu. The migration of procurement away from Western Electric after divestiture was significant and sudden; by March of 1986, for example, AT&T's share of Pacific Telephone's procurement fell to less than 50 percent, from a pre-divestiture level of 90 percent.[36]

It appears that technological progress in these areas has not suffered as a result of divestiture. Indeed, as far as the diffusion of technological change is concerned, society is clearly better off. As Sirbu notes, the question of whether divestiture has had an impact on earlier steps in the process of technological change—invention and innovation—is more difficult to evaluate. However, judging by the levels of the available objective indicators, the future looks promising. As Charles Brown notes elsewhere in this volume, total R&D in the firms that comprised the pre-divestiture Bell System has increased substantially.[37] Moreover, the incentive for independent manufacturers to invest resources in invention and innovation has increased as the enormous Bell market has opened up and as AT&T's long-distance competitors have made substantial investments.[38] AT&T's R&D may now emphasize applications to a greater degree than in the past, and pure research into areas far afield from telecommunications may not receive the attention it once did at Bell Labs. However, a system of monopoly control over an industry, rationalized by the supply of a public good—pure scientific research—and funded by telephone customers' dollars, never fit comfortably with this country's capitalist philosophy. This kind of research is better funded through the National Science Foundation.

Often forgotten in debates over the effects of the divestiture is the fact that the 1956 consent decree effectively prohibited AT&T from unleashing the resources of Bell Labs on unregulated markets. A robust, highly successful computer industry developed in an environment free from the telephone company's monopoly interference. With emerging competition in long-distance, divestiture made it possible to eliminate the line-of-business restrictions on AT&T. At the same time, monopoly local exchange customers were protected from funding cross-subsidies by maintaining the 1956 decree's line-of-business restrictions on the divested BOCs, who lacked expertise in R&D and manufacturing anyway.[39]

Several of the individual examples of post-divestiture technological

change cited by Sirbu deserve brief comment. Events in the Centrex market illustrate that the theory of the antitrust case and its actual implementation did not coincide perfectly. Boundaries between competitive and monopoly services are often difficult to draw. This is particularly true when there is rapid technological change. At divestiture, the boundary problems were, for the most part, resolved satisfactorily. Under the theory of the case, AT&T was to receive the competitive, or potentially competitive, Bell System lines of business. However, Centrex competes directly with customer premises switches. This is true even though the functional capacity for Centrex is located in the monopoly local switch. The BOCs were given Centrex at divestiture, despite its competitive nature, because of the technical difficulty inherent in giving it to AT&T.

As Sirbu notes, prior to divestiture, AT&T had decided to migrate customers from Centrex to PBXs. After *Computer II*, just prior to divestiture, the BOCs understandably began to market Centrex aggressively and were able to induce AT&T and other vendors to provide the upgrades to Centrex necessary to compete with PBXs. Sirbu concludes that "we have seen a wide range of feature enhancements to Centrex which . . . can be directly traced to the new incentives created by divestiture."[40] Left unanswered is whether this is a good thing.

AT&T could have chosen to respond to evolving PBX competition prior to divestiture by upgrading Centrex. It did not do this, even though doing so would have allowed it more easily to cross-subsidize the Centrex service because of the high degree of common costs in local switches. This strongly suggests that Centrex is simply the wrong technological choice, but the BOCs are promoting it for their own strategic purposes. While this does not mean divestiture was a mistake, it does show it was not perfect.

Sirbu blames divestiture for a two-year delay in the implementation of ISDN standards because AT&T lost some control over the standard-setting process. The ISDN standard issue was controversial even before divestiture, and there is no guarantee that an integrated AT&T could have pushed one standard through the standard-setting bodies. This is particularly true given the interplay between domestic and international ISDN standards.[41] Moreover, many of the ISDN standards issues are related to CPE. As Sirbu indicates, the Bell System equipment monopoly was under attack prior to divestiture. This was both because of the successful FCC network interconnection standards and because the Bell System analog technology did not meet with consumer favor.

The standards issue is a serious one. There is no question monopolies have an easier time imposing standards than multiple firms have

in agreeing to them. This may simply be one cost of receiving the benefits that multiple choices provide. It may also be an area in which more government involvement will be required in the future.[42]

Sirbu looks skeptically on BOC participation in the information services markets, correctly pointing out that "for reasons of both policy and the marketplace, it is not clear we would have witnessed any golden age of information services if only the MFJ had not restricted BOC participation" and that "it is not yet clear that the BOCs will find the right technical and marketing strategy to make a success of the information services business." This is a refreshing rebuttal of the BOC conventional wisdom.

Indeed, Sirbu could have gone even further to point out that the French videotex system, which he notes is used by the BOCs as an example for the U.S. to emulate, actually provides strong evidence that U.S. technology has not suffered as a result of the divestiture. Growth in usage of the French Teletel system for services other than directory information is primarily in the business market.[43] U.S. businesses already have widespread access to a wide variety of information services through PCs found in virtually any office.[44] Most non-directory services used by residential customers in France are for "chat lines" and basic sports, health, and travel information which are provided in this country at much less cost through universally available audiotext services or 800 Services. As for directory assistance, the operator-provided service in France is notoriously poor, Minitel customers are not issued the White Pages, and Minitel directory assistance is free.[45]

Sirbu finds good news and bad news in the manufacturing ban. The good news is that "without proprietary interests in any particular technology, the RBOCs, through their agent, Bellcore, have been the most fervent proponents in the U.S. telecommunications industry of compatibility standards." Loss of compatibility was a major concern at the time of divestiture. The post-divestiture experience shows that this concern has been addressed adequately. Although interexchange carriers and the BOCs have numerous disagreements over public policy issues, engineering-level working relationships are quite good.

The bad news, Sirbu believes, is that the decree's manufacturing ban impedes the flow of information between the BOCs and their equipment suppliers and prevents the local exchange carriers from appropriating the full benefits of R&D activity. However, there are arguments on the other side. Regulators can induce the BOCs to spend R&D dollars on applied telecommunications research simply by allowing the BOCs to recover the costs from their monopoly customers. This is a luxury most firms in the economy do not enjoy. Financial integra-

tion by the BOCs into manufacturing would allow information to flow only at the expense of creating the same incentives for self-dealing and discrimination that existed prior to divestiture. The costs of this must be weighed against any speculative gains from direct BOC involvement in manufacturing. Moreover, the costs are speculative. Vertical integration is not the only mode of organization in telecommunications. MCI, for example, owns no interest in any manufacturer. Yet, as Sirbu points out elsewhere in his discussion, MCI has access to state-of-the-art switching and transmission technology.

The technological benefit/cost ratio from divestiture seems quite high. Diffusion of technology increased dramatically. The evolving post-divestiture market structure seems conducive to additional gains in invention and innovation. No change of the magnitude of divestiture will be perfect, but the single largest bit of industrial policy attempted in this country to date appears to have worked.

ENDNOTES

1. Amendment of Section 64.702 of the Commission's Rules and Regulations (Third Computer Inquiry), Report and Order, 104 FCC 2d 958 (1986). *Vacated and remanded California v. FCC* No. 87-230 (9th Cir.) June 6, 1990.

2. *United States v. Western Electric Co.*, American Telephone & Telegraph Co., 552 F. Supp 131 (D.D.C. 1982).

3. Final Decision, Amendment of Section 64.702 of the Commission's Rules and Regulations *(Computer Inquiry II)*, 77 FCC 2d 384 (1980), *on recon.*, 84 FCC 2d 50 (1980), 88 FCC 2d 512 (1981), *aff'd sub nom. Computer and Communications Industry Association v. FCC*, 693 F. 2d 512 (1982), *cert. denied*, 461 U.S. 938 (1983).

4. Use of the Carterfone Device in Message Toll Telephone Service, 13 FCC 2d 420 (1968).

5. Proposals for New or Revised Classes of Interstate and Foreign MTS and WATS, 56 FCC 2d 593 (1975), 57 FCC 2d 716 (1976).

6. North American Telecommunications Association, "1983 Telecommunications Equipment Industry Statistical Review," Tech. report, North American Telecommunications Association, 1984.

7. Eric Nelson, "PBX and Key Systems: The State of the Marketplace," *Telecommunications* (June 1989), 23:6.

8. Inan Czatdana, "Carriers Plan $24 Billion Outlay in 1986," *Telephony*, January 13, 1986, pp. 32 ff.

9. William H. Davidson, "A Comparative Assessment of National Public Telecommunications," NTIA Submission, April 9, 1990, p. 8.

10. Abudi Zein, "Switched in Time?" *Data Communications*, October 1, 1987, pp. 68 ff.

11. For example, see Peter Huber, *The Geodesic Network* (Washington, D.C.: 69O, 1987).

12. G. Pinkham, "An lntelligent Move," *Telephony*, May 15, 1989, pp. 40ff.

13. Some observers have pointed to the explosion in PCs in the corporate world and the relative decline of the mainframe and draw an analogy to suggest that putting intelligence in the network is a mistake. A more nuanced reading of the record reveals that more and more PCs are being hooked into networks, with specialized shared machines, such as file servers, print servers, database servers, and communications servers, providing support to applications through standardization protocols. Similarly, the communications network must move towards a model in which central office switches act as servers for carrier, enhanced services provider, and end-user application.

14. l. Dorros, "Evolving Capabilities of the Public Switched Telecommunications Network," in J. Schement et al., eds., *Telecommunications Policy Handbook* (New York: Praeger, 1982).

15. As of June 1987, nearly 20 percent of BOCs' subscriber lines terminated on electromechanical switches.

16. Larry Lannon and lnan Czatdana, "Spending Falls Gently in 1988," *Telephony*, January 18, 1988, pp. 36 ff.

17. John Foley, "Supernode to CO's Rescue," *Communications Week*, April 25, 1988, pp. 25ff.

18. See, for example, the debate over the introduction of 800 number call processing by the BOCs and its impact on call processing times. Kathleen Killette, "Carrier Flap Persists Over Proposed 800 System," *Communications Week*, April 18, 1988, pp. 37 ff.

19. Mark Rockwell, "lntelligent-Net Basics to Come Next Year," *Communications Week*, March 27, 1989, pp. 2 ff.

20. Michael Warr, "Bellcore Slows Program for Network Evolution," *Telephony*, May 15, 1989, p. 12.

21. Paulina Borsook, " 'U' Marks the Criticai Spot for USer Interfaces to lSDN," *Data Communications* (October 1987), 16(11):70.

22. NTlA, NTlA Trade Report, Assessing the Effects of Changing AT&T Antitrust Consent Decree, Washington, D.C., 1987, Special Publication 87-19.

23. "Pacific Telesis to Get Option for Sake in Group W. Cable Arm," Dow-Jones Newswire, April 21, 8:09 A.M., 1989.

24. Federal Communications Division, Common Carrier Bureau, lndustry Analysis Division, "AT&T Share of Interstate Switched Market," June 15, 1989.

25. Equal access was available on only 3.8 percent of all BOC lines on December 31, 1984. By the end of 1986 this had jumpcd to 74.4 percent and by the end of 1989 reached 94.9 pcrcent. *FCC Statistics of Common Carriers*, 1988/1990 edition, p. 308.

26. M. Kerner, H. L. Lemberg, and D. M. Simmons, "An Analysis of Alternative Architecture for the lnteroffice Network," JEEE JSAC, vol. SAC-4, no. 9, December 1986, pp. 1404–13.

27. Based on calculations by D. Reed and M. Sirbu.

28. M. Sirbu, D. Reed, and F. Ferrantz, "An Engineering and Policy Analysis of Fiber Introduction into the Residential Subscriber Loop," *Journal of Lightwave Technology* (November 1989).

29. While other BOCs have begun videotex trials, in October 1989, Pacific Telesis announced it had abandoned plans to test a videotex gateway service because market research turned up insufficient numbers of potential information providers.

30. The reason for this is that the independents had not installed an interim generation of electronic analog switches (e.g. the 1AESS) like the RBOCs. Replacement of electromechanical by digital switches is justifiable almost entirely in terms of the superior economics of digital switches: hence the more rapid rate of digital switch installation by independents.

31. Also prices in international markets for switches equipment, which tend to be dominated by non-U.S. or Canadian competitors, have experienced price reductions comparable to those in the United States.

32. The basic advantage of CPE lies in the ability of purchasers to restrict user options. Technology in the public network must inevitably accommodate a very wide range of manufacturers and generations of equipment. The cost of doing so, which rises exponentially with the number of alternatives accommodated, accounts for the poor performance of network based solutions compared to CPE.

33. Internationally, rapid ubiquitous ISDN deployment (as in Japan) appears to depend much more on government subsidy and commitment than industry structure.

34. See, e.g., Defendant's Pretrial Brief, *U.S. v. AT&T*, Civil Action no. 74-1698, December 10, 1980, pp. 199–210.

35. See, e.g., Plaintiff's First Statement of Contentions and Proof, *U.S. v. AT&T*, Civil Action no. 74-1698, November 1, 1978, at pp. 258-514 for a discussion of the Justice Department's equipment foreclosure case.

36. Statement of Gary McBee, Pacific Telesis, to the House Subcommittee on Telecommunications, Consumer Protection and Finance, March 13, 1986, p. ii. Also see, 'Digital Switch Business Sees More Competition," *The Wall Street Journal*, January 23, 1986, p. 6.

37. Also see letter from Gerald M. Lowrie, Senior Vice President of AT&T, to Alfred C. Sikes, Assistant Secretary of Commerce for Communications and Information, Re: Docket No. 81267-8267, March 10, 1989.

38. MCI's investment in its network rose dramatically in the first full year after divestiture was announced, and continued to rise for several years thereafter. See MCI Annual Reports.

39. AT&T's difficulties in penetrating the computer market to date, even with its R&D and manufacturing expertise, may say something about the benefits of unleashing the BOCs to participate in manufacturing.

40. The fact that the BOCs were able to induce their suppliers, primarily among them AT&T, to upgrade Centrex shows that they have substantial ability to control the evolution of technology in their networks, the manufacturing ban not withstanding.

41. See Federal Communications Commission, First Report In the Matter of Integrated Services Digital Networks, April 12, 1984.

42. Jean Tirole notes that "the adoption of AM stereo radio broadcasting in the U.S. seems to have been hampered by the lack of standards and the concommitant hesitancy of stations and listeners to sink money into technological losers." *The Theory of Industrial Organization* (Cambridge, Mass.: MIT Press, 1988), p. 405. This is a case where the FCC explicitly decided not to set a standard.

43. "Minitel Loses Fad Image, Moves Towards Money," *MIS Week*, September 5, 1988.

44. NTIA Information Services Report, U.S. Department of Commerce, Reg. 4 No. 88-235, August 1988.

45. Justine DeLacy, "The Sexy Computer," *The Atlantic Monthly*, July 1987.