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Competition and Deployment of New Technology in U.S. Telecommunications

Howard A. Shelanski†

Participants in regulatory and antitrust proceedings affecting telecommunications have, with increasing frequency, asserted that policy decisions designed to promote or preserve competition will have unintended, negative consequences for technological change.[1] The goal of this study is to determine the initial presumption with which regulators and enforcement agencies should approach such contentions. To that end, this Article examines how the introduction of new technology in U.S. telecommunications networks has historically related to market structure. It analyzes deployment data from a sample of technologies and finds that innovations have been more rapidly deployed in telecommunications networks the more competitive have been the markets in which those networks operated. This positive correlation between competition and adoption of new technology suggests that regulators and enforcement officials should be wary of claims that, by adhering to policies designed to preserve competition, they will impede firms from deploying innovations or bringing new services to consumers.[2]

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[1] Cellular Telecommunications Industry Association, 13 FCC Rec 25132, 25157 (1998); Comments of GTE, WT Docket No 98-205, 20 (2000); Reply Comments GTE, WT Docket No 98-205, 16–19 (1999); Comments of Cellular Telecommunications Industry Association, WT Docket No 98-205, 3 (1999); Comments of Southern Bell Communications Wireless Corp, WT Docket No 98-205, 4, 11; Comments of Omnipoint Communications, Inc, WT Docket No 98-205, 4 (1999); Comments of Rural Telecommunications Group, WT Docket No 98-205, 6 (1999); Comments of Western Wireless Corp, WT Docket No 98-205, 9 (1999).

[2] It is important to note that deployment of new technology may bear only an indirect relationship to development of new technology. This study's results, and the policy recommendation they yield, thus apply more to the relationship between market structure and commercial implementation of new technology than they do the relationship between market structure and the process of innovation itself. The term "innovation" in this article thus refers to deployment, rather than creation, of new network technology.

The burden should rest with parties whose actions would concentrate markets to demonstrate offsetting benefits from innovation. There will certainly be instances when good evidence supports the likelihood of a tradeoff between competition today and new technology tomorrow. For example, financial and technical analysis might demonstrate that deployment of an innovative facility or service is truly contingent on achieving larger scale or unifying complementary assets. Or, data might show that consumers are beginning to consider new services as substitutes for established ones and that markets should be defined more flexibly and dynamically. When there is good reason to believe that tradeoffs between competition and technological change both exist and will produce net economic benefits, regulators should not be so focused on short-term market structure and performance that they miss greater dynamic benefits. Any presumption in favor of preserving existing competition must therefore be subject to rebuttal.

The difficulty in establishing a sturdy presumption about the interaction between market structure and innovation stems from the complexity of the underlying relationship. Changes in market structure do not completely, or perhaps even significantly, explain variation in rates of technological deployment. Market structure might correlate with other variables that simultaneously affect innovation. For example, in a regulated industry like telecommunications, it is particularly likely that pricing rules, service requirements, subsidy flows and other regulatory and institutional factors affect technological decisions. Because those variables are not incorporated into this study's analysis, neither the comparative importance nor causal significance of market structure for innovation can be determined here. This Article's results therefore cannot on their own be interpreted to support stricter antitrust enforcement or more aggressive market-entry regulation in the name of innovation. The historical correlation between market structure and innovation does, however, allow policy makers to discern whether competition and technological progress have consistently converged or diverged and, on that basis, to adopt guiding presumptions and assign burdens of persuasion when parties to a proceeding contend that those objectives will conflict.

Part I of this Article discusses the emergence of innovation as a central concern in telecommunications regulation and describes how, in several important proceedings, parties have portrayed innovation and competition as being in conflict. Part II briefly examines the theoretical and empirical economic literature on the relationship between market structure and technological change. That discussion shows the difficulty of creating strong, broadly applicable presumptions about how policies affecting competition will in turn affect innovation. Part III then looks at the telecommunications sector to see how, at a very general level, market structure has related to the deployment of new technology. Examining a sample of ten significant telecommunications technologies, Part III describes the structures of the markets in which manufacturers and telecom service providers developed and deployed those technologies, and then identifies the rate at which each innovation was adopted. Part IV concludes, based on the historical data, that regulators should adopt a rebuttable presumption against claims that competition will conflict with technological advancement in the telecommunications industry.

I. INNOVATION AND TELECOMMUNICATIONS REGULATION

Policy makers have long understood that technological progress is essential for long-term economic expansion. Recently, however, trends in biotechnology, telecommunications, computers, and the complex of enterprises surrounding the internet have made the dividends of technology front-page news. "High-tech" industries—aerospace, telecommunications, biotechnology, and computers—have increased their aggregate share of U.S. manufacturing output more than 50 percent since 1980.[3] And the number of patents granted annually in the United States, which first surpassed 100,000 in 1994, reached almost 170,000 in 1999.[4]

Technology's perceived role in the recent, long cycle of growth in the U.S. economy has caused policy makers and consumers alike to pay greater attention to how innovation can increase economic welfare. One manifestation of this attention to innovation is heightened sensitivity to whether the goals or presumptions of existing public policies might conflict with the goal of technological progress.[5] Whether regulators must sometimes make tradeoffs between innovation tomorrow and efficient resource allocation

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[3] *Economic Report of the President: Transmitted to the Congress February 1999* 171 (GPO 1999).

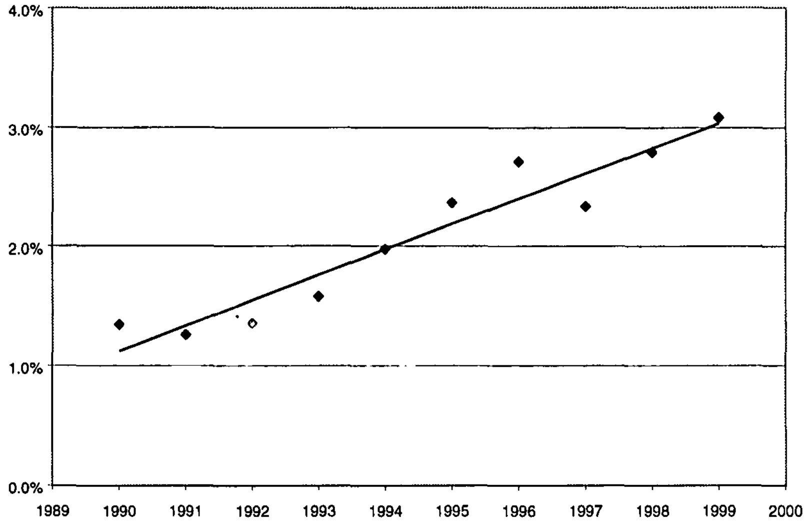
[4] Id at 172; U.S. Patent and Trademark Office, *1999 Patent Statistics Announced,* Press Release #00-16 (Mar 2, 2000), available online at <http://www.uspto.gov/web/offices/com/speeches/00-16.htm> (visited May 30, 2000).

[5] *Economic Report of the President* at 173–93 (cited in note 3).

today has been debated in such diverse contexts as, for example, environmental regulation and antitrust policy.[6]

The question of how policy affects technological innovation has become particularly salient in the telecommunications sector. In the last 20 years this industry has embraced fiber optics, created mass-market wireless services, and deployed the essential infrastructure for the internet, to name just a few developments. Indeed, the telecommunications industry has been responsible for a growing share of patents issued in the United States (see Figure 1). For the most part, however, fostering new technology was an implicit objective in telecommunications policies that were more expressly concerned with competition and market structure. The emergence of innovation as a principal objective of its own in regulatory debates and antitrust enforcement decisions is a quite recent development.

Figure 1: Telecommunications Patents as Percentage of All Patents Granted in the U.S.[7]



Several kinds of policy arguments hinge on innovation. The most common form of the argument, made by participants in recent proceedings at the Federal Communications Commission ("FCC," "Commission") and the Department of Justice, is that

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[6] See, for example, id at 188–211.

[7] US Patent and Trademark Office (August 1999) *Patent Counts by Class by Year, Jan 1977–June 1999.*

innovation may suffer if regulators focus too narrowly on preserving or improving competition in existing markets. For example, FCC regulations bar a single wireless carrier from holding licenses to use more than 45 MHz of the 180 MHz of cellular and PCS spectrum available in a given geographical market.[8] This "spectrum cap" ensures that each geographical market can have at least four competitors providing mobile phone service. In the FCC's 1999 proceedings on whether to retain the 45 MHz cap[9], several carriers argued that consolidation of competing licenses is a necessary condition for the development of innovative wireless data services (so-called "third generation" services).[10] Those carriers argued that without such consolidation, they would be uncertain of having sufficient spectrum capacity for the new services and hence would find it too risky to invest in developing the new technology. In the FCC's recent rulemaking limiting the number of subscribers a single cable company can serve, some cable operators similarly argued that the introduction of broadband and telephone services on cable networks requires large-scale systems.[11]

A related argument is that regulators will harm innovation if they adhere to obsolescent market definitions. MCI and Sprint contended that new technology like the internet protocol is fast making the separate market of "long-distance" telephony a meaningless concept. They argued that blocking a merger based on a soon-to-be-outmoded definition of the relevant market would impede beneficial combinations. MCI and Sprint further argued that even if their merger would have made a meaningfully defined long-distance market more concentrated, such concentration would have enabled the companies to make other markets—like that for local phone service—more competitive through deployment of new wireless technology and other advancements.[12]

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[8] 47 CFR § 20.6 (2000).

[9] See Notice of Proposed Rulemaking, FCC 98-308; Comments of Cellular Telecommunications Industry Association, WT Docket 98-205; Report and Order, 47 CFR Parts 20 and 22.

[10] Cellular Telecommunications Industry Association, 13 FCC Rec at 25157; Comments of GTE, WT Docket No 98-205 at 20; Reply Comments GTE, WT Docket No 98-205 at 16–19; Comments of Cellular Telecommunications Industry Association, WT Docket No 98-205 at 3; Comments of Southern Bell Communications Wireless Corp, WT Docket No 98-205 at 4, 11; Comments of Omnipoint Communications, Inc, WT Docket No 98-205 at 4; Comments of Rural Telecommunications Group, WT Docket No 98-205 at 6; Comments of Western Wireless Corp, WT Docket No 98-205 at 9.

[11] *In the Matter of Implementation of the Cable Television Consumer Protection and Competition Act of 1992*, CS Docket No 98-82, 26 (1999).

[12] See *MCI WorldCom and Sprint*, CC Docket No 99-333, 76 (1999).

The merging parties are thus also asking the Commission and the Department of Justice to trade concentration in one market for competition in another.

The Federal Communications Commission has addressed the above challenges in a case-by-case manner and has generally maintained its emphasis on competition and static efficiency. In the spectrum cap proceeding, the Commission retained the 45 MHz limit in the interests of preserving current competition.[13] But it also pledged to revisit the cap in two years.[14] And, in the meantime, it invited waiver requests from carriers that can show they are moving forward with new services that require additional spectrum. In the cable ownership proceedings,[15] the Commission imposed a subscriber limit, as Congress by statute required it to do. But the FCC also said it would not attribute to an operator's subscriber count any customers to whom it provided only telephone or broadband, but not conventional cable video, services.

The effort in both of the cases above was to preserve competition without blunting incentives to invest in the development and deployment of new technology. But the above examples also show that in telecommunications policy, innovation and its potential tradeoffs will be a recurring issue to which a more informed approach will be necessary. If regulators or enforcement officials focus too rigidly on competition and the immediate benefits of lower prices and higher output, they might in some cases place at risk longer-term benefits of innovation. If, on the other hand, they too readily exchange actual competition for promised innovation, they risk creating market power without deriving any compensating benefit.

Striking the right policy balance is especially challenging where, as in telecommunications, the pace of innovation makes predictions of technological change unusually plausible. Imminent technological developments *will* transform some markets in ways that make current market definitions obsolete. And some innovations *would* occur more rapidly if carriers merged complementary assets. But, although maintaining or increasing competition in existing markets might have costs for innovation in spe-

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[13] See Notice of Proposed Rulemaking, FCC 98-308; Comments of Cellular Telecommunications Industry Association, WT Docket 98-205; Report and Order, 47 CFR § 20, 22 (2000).

[14] Id.

[15] *In the Matter of Implementation of Section 11(c) of the Cable Television Consumer Protection and Competition Act of 1992*, 14 FCC Rec 19098 (1999).

cific cases, it is far less clear that such costs will often be at stake, even in the dynamic environment of U.S. telecommunications. Policy makers concerned with telecommunications would thus benefit from a framework through which to distinguish cases where emphasis on current market structure may have net, long-term costs from cases where it will not. The first step in developing that framework is to determine what the starting presumption of the analysis should be and, correspondingly, where the initial burden of persuasion should rest. The next section surveys existing research on the economics of innovation and examines the guidance it offers for answering the above questions.

II. THE ECONOMICS OF MARKET STRUCTURE AND INNOVATION

Joseph A. Schumpeter wrote in 1942 that, for purposes of economic welfare, "perfect competition is not only impossible but inferior, and has no title to being set up as a model of ideal efficiency."[16] Since that time, scholars have investigated whether, and under what conditions, innovation and allocative efficiency might respond differently to changes in market structure. Schumpeter's argument—that most technological innovation would come from large corporations with market power and organized R&D operations—implied that public policies focusing on current (or "static") competition could have substantial social costs over time.[17] He suggested that the economic conditions that maximize innovation in the long run might not be the same conditions that allocate resources efficiently in the short run.

Schumpeter's conjecture sparked research by economists who sought to identify the market and firm structures most conducive to the production and adoption of new products and processes.[18] The sections that follow briefly survey two areas of that research: studies relating innovation to firm size, and studies relating innovation to market structure. In each case the research reveals

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[16] Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy* at 106 (Harper & Row 3d ed 1942).

[17] Of course, antitrust's competitive ideal has evolved over time. When Schumpeter was writing, the ideal was rivalry among small, atomized economic actors. Any cooperation or concentration that deviated from that standard was inherently suspect. The Chicago School revolution greatly improved understanding of why different market structures might arise in various contexts and reduce rigid adherence to the perfectly competitive model. Competition, because of its benefits for allocative efficiency, nonetheless remained the touchstone of antitrust policy.

[18] For a survey of this literature, see Morton I. Kamien and Nancy L. Schwartz, *Market Structure and Innovation* (Cambridge 1982); William L. Baldwin and John T. Scott, *Market Structure and Technological Change* (Harwood Academic 1987).

some areas of consensus, but more clearly demonstrates ambiguities that make it difficult to craft general presumptions about how firm or market structures affect technological change.

A. Firm Size and Innovation

In several recent proceedings at the FCC, parties have claimed they need to increase the size of their operations in order to deploy advanced technology and provide new services. For example, in the Commission's cable ownership and attribution proceedings, AT&T pledged that expanding the reach of its systems would enable the company to speed the upgrade of its network to provide telephone and high-speed data services.[19] SBC and Ameritech similarly argued in their 1999 merger proceedings that the combination of the firms would speed the deployment of broadband telephony to residential customers.[20]

There has been substantial debate over the relevance of firm size to innovation. Following Schumpeter, some economists have praised large enterprises for their superior ability to attract the financial and human capital, bear the risk, and recoup the investment required for sustained R&D activities.[21] However, other economists have touted small firms as being more creative and more nimble in adapting to changes and opportunities than their larger, more bureaucratic counterparts.[22]

Many empirical studies have addressed the relationship between firm size and innovation. Numerous early studies found that investment in R&D increased steadily with firm size.[23] Whether comparing evidence across industries[24] or within a par-

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[19] *In the Matter of Implementation of the Cable Television Consumer Protection and Competition Act of 1992*, 14 FCC Rec 19014, 19026 (1999).

[20] *In the Matter of Ameritech Corporation*, 2000 FCC Lexis 4765, *3.

[21] See generally John Kenneth Galbraith, *American Capitalism: The Concept of Countervailing Power* at 86–88, (Houghton Mifflin Rev ed 1952); William D. Nordhaus, *Invention, Growth, and Welfare: A Theoretical Treatment of Technological Change* (MIT 1969).

[22] Kamien and Schwartz, *Market Structure and Innovation* at 33 (cited in note 18); Wesley M. Cohen and Richard C. Levin, *Empirical Studies of Innovation and Market Structure*, in Richard Schmalensee and Robert D. Willing, eds, 2 *Handbook of Industrial Organization* 1067 (North-Holland 1989).

[23] See, for example, Ira Horowitz, *Firm Size and Research Activity*, 28 S Econ J 298 (1962) (finding some basis for the belief that bigness favors research); William S. Comanor, *Market Structure, Product Differentiation, and Industrial Research*, 81 Quarterly J Econ 639, 657 (1967) (concluding that while smaller firms often spend as much on research as larger rivals, higher concentration can lead to increased research spending in some situations).

[24] See, for example, P.D. Loeb, *Further Evidence of the Determinants of Industrial Research and Development Using Single and Simultaneous Equation Models*, 8 Empirical Econ 203 (1983) (comparing 303 firms across almost all industrial categories for the year

ticular industry,[25] studies generally showed that R&D was higher in larger enterprises.[26] Other studies, however, found that very small firms were in fact more innovation-intensive than middle-sized firms.[27]

More recent research yields a consensus that, in general, R&D rises only proportionately with firm size, and only up to a point.[28] Moreover, this pattern varies across industries. In the chemical industry, for example, studies have found R&D to increase significantly with firm size, while in other industries such as petroleum, drugs, steel and glass, researchers have found the reverse to be true.[29] But on the whole, economists find that the data best supports proportional increases.[30] Therefore, while a large enterprise might invest more in R&D than a small one, it does not invest more than an equal-sized aggregation of small firms.

Available data and research thus call into question the conjecture that large firms are superior innovators, although studies do not support the contrary view that large firms are bad for technological progress and economic growth. The evidence overall suggests that, to the extent firm size has an effect on innovation, its magnitude and direction depend on associated industry-level variables and are susceptible to very few general presumptions. The results suggest that especially large firms will have no special tendency—nor any predictable reluctance—to engage in in-

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1971); John B. Meisel and Steven A.Y. Lin, *The Impact of Market Structure on the Firm's Allocation of Resources to Research and Development*, 23 Quarterly Rev Econ & Bus 28 (1983) (using data on 1,026 businesses in the year 1974).

[25] See Edwin Mansfield, *Industrial Research and Development Expenditures: Determinants, Prospects, and Relation to Size of Firm and Inventive Output*, 72 J Pol Econ 319 (1964) (evaluating research and development in chemical, petroleum, drug, steel, and glass industries); Henry G. Grabowski, *The Determinants of Industrial Research and Development: A Study of the Chemical, Drug, and Petroleum Industries*, 76 J Pol Econ 292 (1968) (investigating research expenditures in the chemical, drug, and petroleum refining industries).

[26] Cohen and Levin, *Empirical Studies* at 1068 (cited in note 22).

[27] See, for example, John Bound et al, *Who Does R&D and Who Patents?* 1, 21 in Zvi Griliches, ed, *R&D, Patents, and Productivity* (Chicago 1984).

[28] See, for example, F.M. Scherer, *Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions*, 55 American Econ Rev 1097 (1965) (concluding that incentive output increases with first sales, but at less then proportional rates, and raising doubts about whether large firm are as efficient as previously thought).

[29] Edwin Mansfield, *Industrial Research and Technological Innovation*, 43 (Norton 1968) ("[E]xcept for the chemical industry, there is no evidence that the largest firms [in petroleum, drugs, steel and glass] spent more on research and development than did somewhat smaller firms.").

[30] Scherer, *Firm Size, Market Structure* (cited in note 28); see generally Wesley M. Cohen and Steven Klepper, *A Reprise of Size and R&D*, 106 Econ J 925 (1996).

novation, and that small, fringe firms may play important roles over time in technologically advancing markets.[31]

B. Competition and Technological Change

While Schumpeter raised interesting questions about firm scale and innovation, the more troublesome implications for public policy came from his conjecture about the relationship between market structure and technological innovation. Antitrust policy was then, as it is today, grounded in the virtues of economic competition. The idea that competition could impede innovation and reduce long-term economic benefits posed a challenge to the antitrust paradigm.

Like antitrust policy generally, regulatory policy in communications has presumed that market competition benefits economic welfare. For example, in its review of firms' decisions to enter and exit regulated telecommunications markets, the FCC presumes that entry by new competitors benefits the public interest.[32] As a general matter, in conducting its public interest review, the Commission "refrain[s] from requiring new entrants to demonstrate beneficial effects of competition"[33] and presumes that "effective competition directly advances the public interest."[34] The FCC might not favor competitive entry when there is "a showing that competition will produce detrimental effects."[35] And the Commission fully recognizes that not only competition, but also "provision of new technologies and services to the public" serves the public interest.[36] But the stated emphasis in the FCC's public interest determinations, at least in the common-carrier context, has been on competition.

The presumption that increased benefits come from increased competition may be open to question, however, when the policy goal is not just lower prices for a given set of goods produced under a fixed set of technologies, but also efficient innovative activity by firms over time. Theoretical research has shown that, de-

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[31] See, for example, Jon Baker, *Fringe Firms and Incentives to Innovate*, 63 Antitrust L J 621 (1995).

[32] See, for example, *In the Matter of Time Warner Entertainment Co and US West Communications, Inc.*, 8 FCC Rec 7106, 7107–08 (1993); *MTS-WATS Market Structure Inquiry*, 92 FCC 2d 787, 790–91 (1982).

[33] *MTS and WATS Market Structure*, 81 FCC 2d 177, 201 (1980).

[34] *Market Entry and Regulation of Foreign-Affiliated Entities*, 11 FCC Rec 3873, 3878 (1995).

[35] *MTS and WATS*, 81 FCC 2d at 201.

[36] *Time Warner*, 8 FCC Rec at 7107.

pending on various conditions, either monopoly power or competition may increase total innovation.

We can return to Schumpeter's work for arguments supporting firms with market power. Although Schumpeter wrote mostly about large firms and their associated economies of scale for R&D, and their ability to attract capital and talented scientists, his critique of perfect competition and discussion of the benefits of market power suggest that his superior innovators were not only large, but dominant as well.[37] Early theoretical explorations of Schumpeter's claim found that increased competition stimulates greater innovative effort among rivals up to a point, but that innovation actually diminishes once the amount of competition surpasses a certain threshold. Thus, in this model, innovation is weak where there is either no competition or vigorous competition.

Although there have been many advances and refinements in the model described above,[38] the intuition underlying the relationship it shows between market structure and innovation is straightforward. A firm that is engaged in rivalry over market share has incentives to develop new products and processes that will help it to improve or defend its market position. However, a competitive firm also faces higher risk and tighter financial constraints than does a firm with market power. Even if intellectual property rights give the innovator a temporary monopoly, rivals may develop similar or better advances. The risk that another firm will successfully innovate grows with competition and, at some point, the expected return on innovation may not justify the cost.

A monopolist or firm with market power, by contrast, probably has more resources for R&D and a better chance of recouping R&D investment. Large, established firms might be particularly adept at incremental innovation or at commercialization of small firms' inventions. And even a monopolist—especially an unregulated one—has some incentive to engage in cost-reducing innovations. But because a monopolist already has the market share for which competitive firms strive, it might have less incentive to pursue product innovations and improvements than might firms facing competition. Further, a monopolist might have an incen-

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[37] Schumpeter, *Captialism, Socialism, and Democracy* at 106 (cited in note 16).

[38] See, for example, Jennifer F. Reinganum, *The Timing of Innovation: Research, Development and Diffusion*, in Richard Schmalensee and Robert D. Willing, eds, 1 *Handbook of Industrial Organization* (North Holland 1989).

tive to innovate strategically to protect its profits and market power rather than to benefit consumers.

Unfortunately, empirical data do not resolve the ambiguous theoretical relationship between competition and innovation. Many analyses supported the Schumpeterian view by finding a positive correlation between market concentration and R&D investment.[39] Others concluded that concentration has a negative effect on innovation.[40] A study by F.M. Scherer found that the relationship between market structure and innovation follows an "inverted-U" pattern: innovation is low at high levels of competition, reaches its peak at intermediate levels of oligopoly (e.g. where the four leading firms control roughly half the market), and then falls off as market structure approaches monopoly.[41]

Several studies reproduced and confirmed Scherer's results,[42] while others added complexity to the findings. When researchers controlled for industry-level factors like appropriability conditions and "technological opportunity,"[43] the overall effect of concentration was ambiguous in the range of market structures studied.[44] Several other studies question more generally whether there is an optimal market structure for promoting innovation, but they agree with the studies showing a non-linear, inverted-U relationship in that they find little evidence that high levels of either competition or concentration are particularly conducive to innovation.[45]

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[39] See, for example, Mansfield, 72 J Pol Econ 319 (cited in note 25); Horowitz, 29 S Econ J 298 (cited in note 23).

[40] See, for example, Arun K. Mukhopadhyay, *Technological Progress and Change in Market Concentration in the U.S., 1963-77*, 52 S Econ J 141 (1985); Barry Bozeman and Albert N. Link, *Investments in Technology: Corporate Strategy and Public Policy Alternatives* (Praeger 1983); Oliver E. Williamson, *Innovation and Market Structure*, 73 J Pol Econ 67 (1965).

[41] See F.M. Scherer, *Market Structure and the Employment of Scientists and Engineers*, 57 American Econ Rev 524 (1967).

[42] See, for example, Wesley M. Cohen, Richard C. Levin, and David C. Mowery, *R&D Appropriability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypotheses*, 75 American Econ Rev Papers and Proceedings 20 (1985).

[43] "Technological opportunity" is a murky concept that includes the range and maturity of technologies used in an industry as well as industry factors affecting the prospects for earning a return on further innovations.

[44] See Wesley M. Cohen & Richard C. Levin, *Handbook of Industrial Organization* at 1074–77 (cited in note 22).

[45] Id.

C. Lessons from the Economic Literature

Two lessons for telecommunications policy makers emerge from the economic literature discussed above. The first is that there is no rule of thumb for how concentration will affect innovation comparable to the presumption about how concentration will affect prices and output levels. In a technologically dynamic industry like telecommunications, regulators cannot ignore claims that innovation may go hand in hand with increased concentration. Nor, however, can regulators take such claims at face value. The second lesson, which follows from the first, is that policy makers must make a careful, case-by-case analysis before they can accept a tradeoff between competition and innovation.

Such case-specific analysis can be difficult because the innovation at issue will frequently be speculative, the need for the market-concentrating transaction will be uncertain, and the ultimate costs and benefits will be difficult to ascertain and balance in advance. Meanwhile, regulators will probably have an easier time assessing whether increased concentration will raise prices and reduce output levels in the relevant markets. The combination of speculative benefits and comparatively certain costs might seem itself to determine that the presumption should be against allowing concentration. But in industries like telecommunications, whose performance is arguably judged as much by the pace of innovation as by price and output levels,[46] the more conservative and better-lit path will not always be the one that maximizes economic welfare over time. Given the ambiguity both of economic theory and of the available empirical data on the relationship between market structure and innovation, more industry-specific analysis is necessary.

The next section of this Article takes a step in that direction. It looks at the U.S. telecommunications industry and examines how, in that particular context, market structure and deployment of innovative technology have historically correlated.

III. DEPLOYMENT OF NEW TECHNOLOGY IN U.S. TELECOMMUNICATIONS NETWORKS

This section discusses ten significant cases of technological innovation in U.S. telecommunications networks and examines how deployment rates for those innovations varied with market

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[46] See Figure 1 (showing how telecommunications patents have become an increasing percentage of all patents granted in the US).

structure. The markets at issue range from pure monopolies to relatively competitive oligopoly structures. For example, touch-tone dialing was implemented under monopoly conditions, while digital wireless telephony took hold under competition among several firms. For purposes of this section's analysis, market structures are divided into three categories: monopoly, concentrated oligopoly (two or three firms), and competitive oligopoly (more than three firms).

Of the ten technological cases examined, four involve innovations deployed in monopoly markets, three address innovations deployed under concentrated oligopoly, and three involve technologies deployed in comparatively competitive oligopoly markets. This section will first discuss the technological cases, beginning with those involving monopolistic markets. The discussion of each case will explain the technology at issue, describe the market structure of the industry that deployed the technology, and examine the rate at which the industry incorporated the technology into its network. This section will then compare the cases to determine how market structure and technological deployment have correlated in the American telecommunications industry.

A. Technology Cases

1. Deployment under monopoly conditions.

The four sample technologies deployed in monopolistic markets were touch-tone dialing, digital stored-program-control switching, ISDN transmission, and electronic stored-program-control switching. The deployment times for those technologies, defined as the time it took for each to be deployed in thirty percent of the relevant network points,[47] were respectively four,

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[47] The technologies examined differ in the parts of the network relevant to measuring their adoption and implementation. For example, customer lines are a reasonable metric for automatic switching, stored-program control, and touch-tone access because their impact is felt directly by an individual customer. It is at the line level that bypassing a live operator and faster dialing are noticed. Central offices (the facilities where switches are located) are taken as the relevant network points for digital switching, SS-7 signaling, and ISDN capability (although percentage of lines covered might also be a good measure of ISDN deployment). Subscribers are the measure for coverage by digital wireless networks. Percentage of total route miles is the measure for deployment of fiber-optic transport. And finally, percentage of homes on the network that can receive DSL and cable-modem transmission are used as the metric for deployment of those services. As a comparison point across all technologies, this paper looks at the time it took for a particular technology to be adopted in 30 percent of the relevant network points. That benchmark is arbitrary, but is designed to capture a point at which a technology has taken hold without requiring that it have become dominant.

seven, nine, and fourteen years. More detailed discussions of each case follow.

a) Touch-tone dialing. AT&T introduced touch-tone dialing, or dual tone multi-frequency ("DTMF") dialing, in 1963.[48] The Bell companies deployed touch-tone during a time when they had a monopoly over both telephone services and, through AT&T's Western Electric manufacturing division, the supply of the technology and equipment necessary to provide those services.

Touch-tone dialing reduced costs for both service providers and customers by reducing the time and network resources needed to complete a call. Turning the dial of a conventional rotary telephone produces pulses that open and close circuits to the central office, with the number of pulses representing the number dialed. This method of transmitting a phone number requires the caller to wait for the dial to reset itself after each digit. With touch-tone dialing, buttons transmit varied tones that represent different numbers. A single tone substitutes for a series of pulses, so the ten digits that take a switch more than 11 seconds to process when dialed from a rotary phone take only 1 second from a touch tone phone.[49] Touch-tone dialing, therefore, requires fewer switching and transport resources and leads to more rapid call completion.

Bell Labs developed DTMF in the late 1950s and conducted technical trials from 1959 to 1961.[50] The Bells first deployed touch-tone service commercially in 1963, and by 1976 approximately 70 percent of its lines could receive touch-tone service (Figure 2).

b) Digital switching. Another technology that was implemented under monopoly conditions was digital switching. Like touch-tone dialing, digital switching could improve network efficiency, although without the immediate consumer benefit of touch-tone. By the 1970s, telecommunications providers were converting long-distance transmission lines and lines connecting central offices from analog transmission to digital signaling (to be

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[48] See See Amos E. Joel, Jr. and G. E. Schindler, Jr, eds, *A History of Engineering and Science in the Bell System: Switching Technology (1925–1975)* 336-43 (Bell Telephone Libraries 1982).

[49] Annabel Z. Dodd, *The Essential Guide to Telecommunications* 110 (Prentice-Hall 1999).

[50] Joel and Schindler, *Switching Technology* at 337 (cited in note 48).

Figure 2: Touch Tone[51]

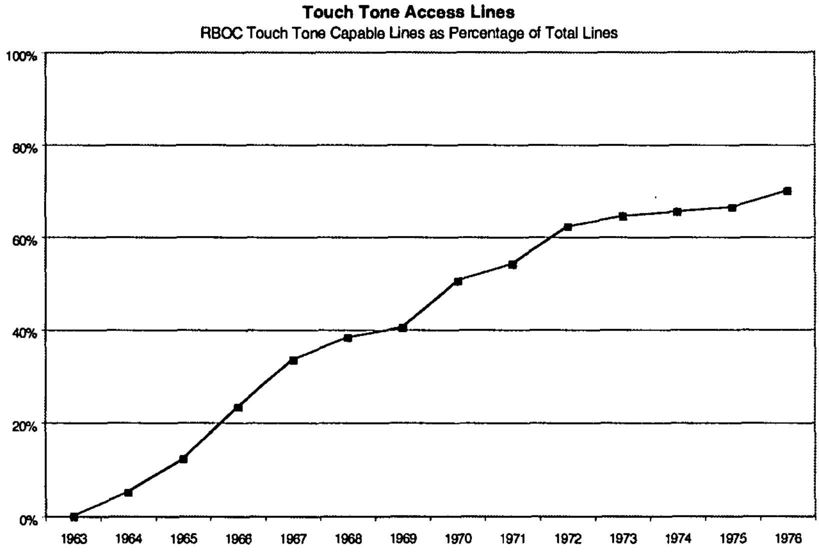
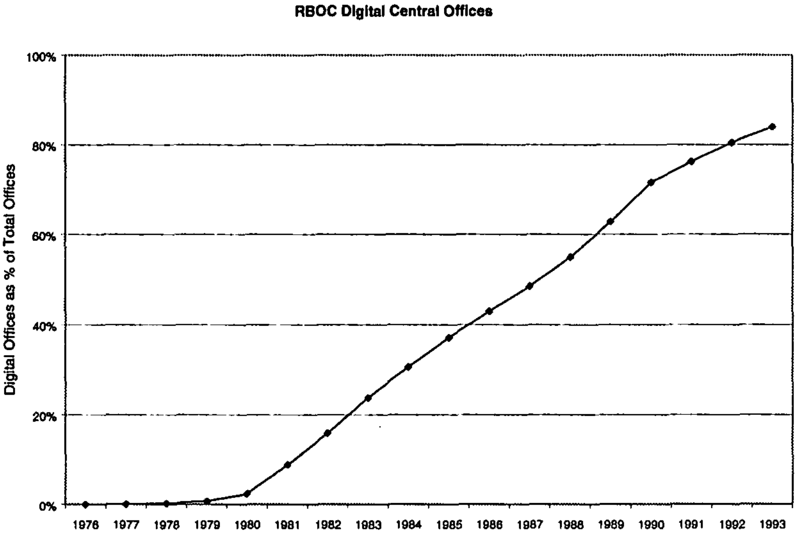


Figure 3: Digital Switching[52]



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[51] Data for this case is number of lines served by touch-tone capable central offices compared to the total number of telephone lines. Joel and Schindler, *Switching Technology* at 343 (cited in note 48); AT&T Co Comptroller's Accounting Division, *Bell System Statistical Manual (1970–1981)* 511 (1982).

[52] Data for this case is the number of Bell system central offices that are digital stored program control: FCC, *1999 Trends in Telephone Service*, Table 18.1 (1999), available

discussed, *infra*).[53] When providers used conventional electronic switches with digital lines, signals had to be converted between digital and analog many times as the switch routed and connected the signals over the network. For example, a call that originated as an analog signal over the local loop had to be converted by the central office switch to digital format for transport over a high-capacity ("T1") line to a long distance office. At the long distance office, the signal had to be re-converted to analog format so the long distance switch could process it and then be converted again to digital so the call could move across the long-haul digital lines. From there, the process was repeated on the termination side until the call reached the ultimate recipient. Fully digital switches avoided the need for such conversions except at the very ends of the network and thereby improved the speed and efficiency of switching.

Independent telephone systems and the Bell system both implemented digital switching around 1976. The Bell system first used the No. 4 ESS digital switch for toll (generally long-distance) calls in Chicago in early 1976.[54] An independent system in California, however, was the first to deploy digital switching systems at the local level, also in early 1976.[55] Deployment of digital switching accelerated in the early 1980s and passed the 30 percent level in 1984 (Figure 3).

c) ISDN transmission. A third technology implemented by local exchange monopolies was ISDN transmission. ISDN is "a digital, worldwide public standard for sending voice, video, data, or packets over the public switched telephone network."[56] ISDN was initially seen as the next step in the evolution of the basic voice telephone system. Carriers hoped it would allow users to connect with others on the network and to exchange not just voice, but data as well. It also provided a high-speed service option for customers who desired rapid data transmission in addition to standard telephone service but whose needs (or budgets)

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online at <http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/trend199.pdf> (visited Oct 11, 2000).

[53] E.F. O'Neill, ed, *A History of Engineering and Science in the Bell System: Transmission Technology (1925–1975)* 563 (AT&T Bell Laboratories 1985).

[54] Robert J. Chapuis and Ames E. Joel, Jr., *Electronics, Computers and Telephone Switching* 336 (North-Holland 1990).

[55] Id at 340.

[56] Id at 146.

did not justify the expensive high-speed options (like T1 lines) that until then had been the only options.

Basic ISDN gives users two communications "channels" over one pair of wires, and each channel can be used either for voice or for data.[57] ISDN standards were developed throughout the 1980's and finalized internationally in the early 1990s.[58] Nortel was the first firm to demonstrate a public network telephone call over ISDN in 1987,[59] the same year the technology was first deployed from a local Bell operating company central office.[60] Providing ISDN requires an "SS-7" switch (see *infra*) and additional equipment for receiving and processing ISDN calls at the local central office. By 1997, ISDN was available from nearly 40 percent of RBOC central offices, which translated into coverage for over 70 percent of all lines (Figure 4).

ISDN was deployed at a time when the local telephone monopolies were beginning to be challenged at the periphery. By the early 1990s, for example, competitive access providers offered bypass of the incumbent local networks for long-distance calls. But little competing service for calls between local customers in a region existed.[61] Indeed, by 1995, competitors to the incumbent carriers still had well less than one percent of the local market by revenues and put little competitive pressure on either the basic or enhanced service offerings of the incumbent firms.[62]

d) Electronic stored-program-control. The fourth sample technology that was implemented under monopoly conditions was "electronic stored program control" switching. In the first automatic-dial systems, each number dialed on a telephone moved equipment in the switch to make a connection. By the time a customer dialed a full sequence of numbers, the switch would have established a path—a series of connections—to the number

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[57] ISDN comes in two modes: basic rate and primary rate. Basic rate ISDN provides two 64 Kbps channels and one 16 Kbps channel for signaling or data, for a total speed of 144 Kbps. Primary rate ISDN provides 23 channels and a 16 Kbps signaling/data channel for a total speed of 1.54 Mbps.

[58] Dodd, *Essential Guide to Telecommunications* at 147 (cited in note 49).

[59] Id.

[60] Data is the number of RBOC central offices that offer ISDN: FCC, 1999. *1999 Trends in Telephone Service*, Table 18.2 (cited in note 52).

[61] See Howard A. Shelanski, *A Comment on Competition and Controversy in Local Telecommunications*, 50 Hastings L J 1617, 1631 (1999).

[62] Industry Analysis Division Common Carrier Bureau FCC, *Local Competition Report: August 1999*, <http://www.fcc.gov/cdo/stats> (visited Sept 29, 2000).

Figure 4: Central offices offering ISDN service[63]

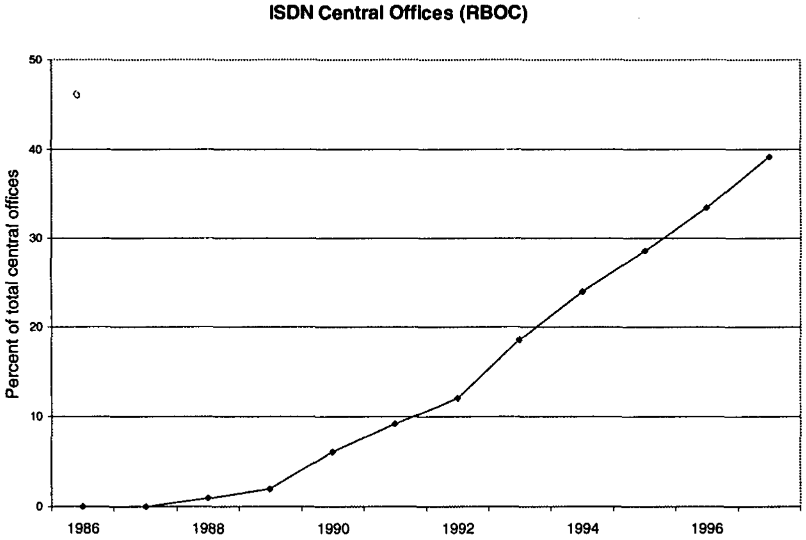
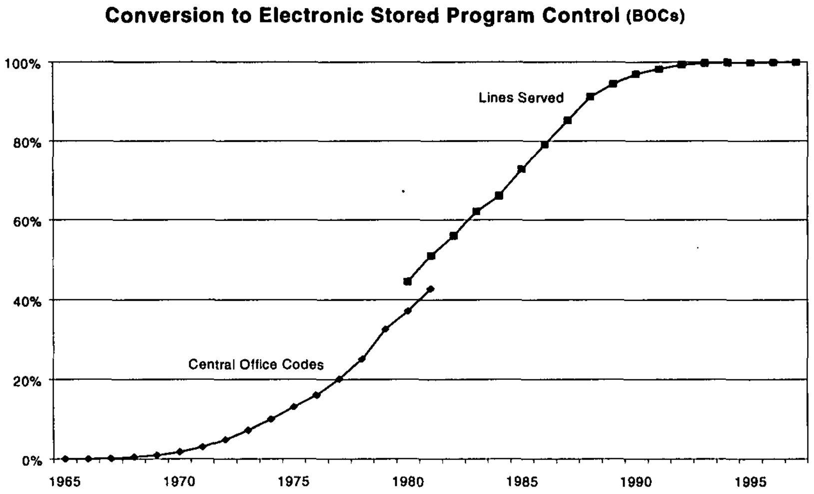


Figure 5: Electronic Stored Program Control[64]



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[63] FCC, *1999 Trends in Telephone Service*, table 18.2 (cited in note 52).

[64] Case data represents the number of access lines served by electronic stored program control central offices. *Bell System Statistical Manual (1950–1981)* at 511 (cited in note 51). Katie C. Rangos, *Infrastructure of the Local Operating Companies* (Industry Analysis Division, Common Carrier Bureau, FCC 1999), <http://www.fcc.gov/ccb/stats> (visited Sept 18, 2000).

dialed. A stored program control ("SPC")[65] switch stores and processes an entire number sequence before instructing the switch how to route the call. This routing method greatly expands the capacity of central offices by using switches more efficiently.

In the early 1950s, Bell Labs and Western Electric Company undertook a massive research effort to develop a stored program control system.[66] They devoted four thousand man-years of work and more than $500 million over the course of a decade to put the Electronic Switching System 1 ("ESS-1") into commercial operation, which they did starting in Succasunna, New Jersey on May 30, 1965.[67] Stored program control systems were quickly put into use throughout AT&T and, to a lesser extent, independent networks. By 1979, over 30 percent of central office switches used electronic stored program control (Figure 5).

2. Deployment under concentrated oligopoly conditions.

Just as the data discussed above show deployment times for new technologies to vary under monopoly conditions, the data from this study's sample also shows the speed of implementation to vary when a modest degree of competition exists in the relevant market. Three sample innovations, fiber-optic transport, SS-7 signaling, and automatic switching were deployed in markets that were concentrated but not monopolistic—i.e. that had two or three firms in competition. The times for deployment to reach 30 percent of the relevant network points varied from four years for SS-7 signaling, to six years for fiber-optic transport, to twelve years for automatic switching.

a) SS-7 signaling. A telephone system needs some form of signaling to alert the switch and customer-end equipment that a call is coming in, to route a call over the network, and to monitor the status of a line (e.g. to see if it is busy). Until recently, signaling information traveled over the same paths that carried telephone conversations—so-called "in-band" signaling. To take the most basic example, in the early days of telephony a caller would contact a central office operator (by pushing a button or turning a crank) and tell the operator whom she wanted to call.

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[65] A stored program control is "routing of a phone call through a switching matrix. . . handled by a program stored in a computer like-device, which may well be a special-purpose computer" *Newton's Telecom Dictionary*, 805 (Telecom Books 16th ed 2000).

[66] See Chapuis and Joel, *Electronics, Computers and Telephone Switching* at 29–66 (cited in note 54).

[67] Id at 40.

The operator would then pass the information down the line to other operators in other central offices, establish a connection to the called party's telephone, and then allow the caller's transmission to begin. The above steps were eventually automated, but the underlying signals (communicating the "address" of the party being called, telling the destination telephone to ring, etc.) were still carried in much the same, sequential manner as before automation.

In the 1970s, AT&T and Bell Labs developed a new signaling system that was faster and more efficient. Instead of sending signaling information ahead of a call over the voice path, the new technology sent the information over a parallel and separate data path that worked almost simultaneously with the call itself, thereby speeding call routing and transmission.[68] The new system was called common channel interoffice signaling ("CCIS"). AT&T developed CCIS into the more sophisticated and higher speed Signaling System 7 standard, which the International Telecommunications Union ("ITU") approved in 1980.[69] SS-7 was first implemented at the toll (that is, long-distance) level in both AT&T's and competitor's systems. Only in 1987 was it put into use in local offices. By 1991, it was already available in approximately 30 percent of BOC central offices and deployment was well over 90 percent by 1997 (Figure 6).

b) Fiber-optic transport. Another improvement in telephone transmission that took place at about the same time that the shift to SS-7 signaling occurred was fiber-optic transport. Instead of using copper wire to carry calls, fiber-optic technology uses light to transport information through thin filaments of glass. The underlying concept of transmitting voice or data over light is an old one. Indeed, Alexander Graham Bell demonstrated "photophony," the transport of voice over a beam of light, in 1880. Photophony had limited range and was subject to interference by weather and objects. Engineers first experimented with transmitting images over glass fibers in the 1930s.[70] The technical limitations were substantial, however. First, the light sources generated too much "noise;" even though an intelligible light signal could be put onto the glass, the output was often incoherent.

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[68] Dodd, *Essential Guide to Telecommunications* at 126 (cited in note 49).

[69] Id at 132.

[70] Edward Lacy, *Fiber Optics* 14–15 (Prentice-Hall 1982).

Figure 6: SS-7 Signaling[71]

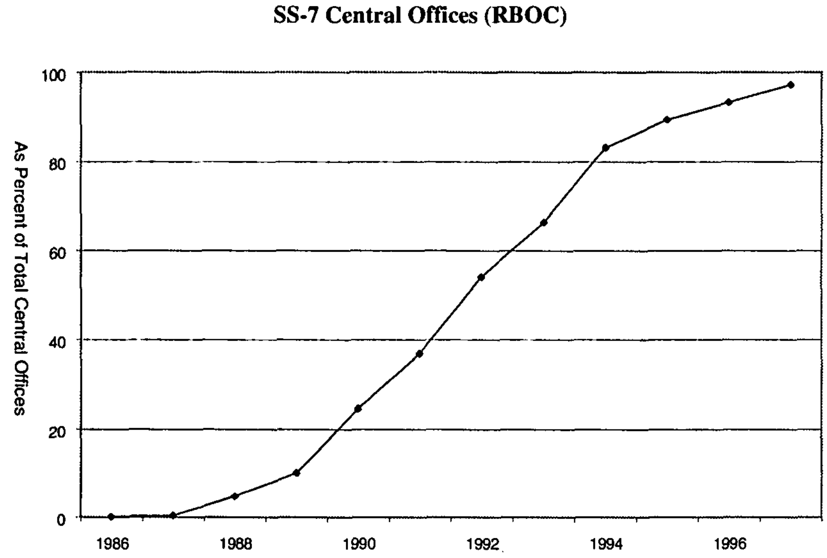
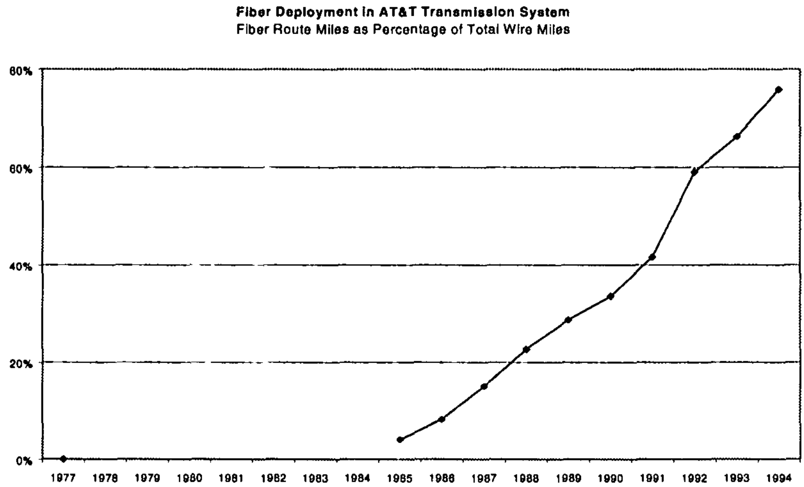


Figure 7: Fiber Optics[72]



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[71] RBOC SS-7 capable central offices as percentage of total: FCC, *Trends in Telephone Service*, Table 18.2 (cited in note 52).

[72] The data for this case is AT&T's fiber miles over total miles of wire. FCC, *Statistics of Common Carriers* Table 14 (FCC 1986–1987), (FCC, 1988–1994); *Statistics of Communication Common Carriers* Table 210 (1986–1994).

Second, the medium carrying the light signal had to be able to carry the signal for long distances. Before 1970, the best-quality glass or lens systems could only carry an intelligible light signal 100 meters.[73] It took the development of lasers in 1958 at Bell Laboratories[74] and the development of "low-loss" optical fibers at Corning Glass Works in the early 1970s[75] to make fiber optics a viable commercial technology.[76]

Fiber optics dramatically cut the costs of transmitting information. Two strands of fiber, each about the width of a hair, can carry more information than a four-inch bundle of copper wires; and it can do so with fewer errors, a longer lifetime, and less susceptibility to interference.[77] The General Telephone Company of California was the first to use fiber optical links in a commercial telephone network, initiating service on April 22, 1977.[78] Under pressure from competitive entrants into the long-distance service market, AT&T began seriously deploying fiber optics in its transmission system in the mid-1980s, reaching 75 percent of total miles of wire by 1994 (Figure 7).

In 1977, when General Telephone first demonstrated fiber optics in the telephone network, AT&T had nearly a complete monopoly over long-distance telephone service. But changes in the structure of the long-distance market had nonetheless been set in motion. In 1959, the FCC began allowing the private use of microwave facilities for transmission of long-distance voice or data traffic.[79] This put limited competitive pressure on AT&T, as large companies could move some of their long-distance traffic to their own networks if AT&T's prices were too high. Over the years that followed, the courts and the FCC proceeded gradually to open the commercial long-distance market to competition. This process concluded when the equal access provisions of the 1984 divestiture bolstered the FCC's 1980 decision to allow open competition.[80] By 1989, when AT&T had deployed fiber optics throughout 30 percent of its network, new entrants deploying

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[73] O'Neill, *Transmission Technology* at 660 (cited in note 53).

[74] Id at 657.

[75] Id at 658.

[76] Lacy, *Fiber Optics* at 15 (cited in note 70).

[77] Dodd, *Essential Guide to Telecommunications* at 49–51 (cited in note 49).

[78] Lacy, *Fiber Optics* at 11 (cited in note 70).

[79] *Allocation of Frequencies in the Bands Above 890M*, 27 FCC 359 (1959).

[80] *United States v American Telephone & Telegraph Co*, 552 F Supp 131, 195 and Appendix B (D DC 1984).

fiber technology had taken nearly 35 percent of the long-distance market.[81]

c) Automatic switching. The third sample technology deployed in highly concentrated, but not monopoly, markets was automatic switching. Early telephone systems required an operator in a central office to connect users manually. Old movie scenes in which efficient operators answer a line, take the caller's request, and then route the line manually through a port in the switchboard give a stylized picture of what was involved. Automatic switching[82] eliminated the caller's interaction with the live operator[83] by allowing customers to dial numbers themselves and by using electromechanical, rather than manual, switches to make connections automatically.

The A.B. Strowger Company developed the first automatic switching systems more than a century ago, motivated in part by Almon Strowger's concern for privacy—he thought the operators were listening in on his calls.[84] The first, primitive automatic exchange for public service went into operation in 1892 in a small, independent telephone company office in La Porte, Illinois.[85] Telephone companies refined the technology and automatic switching came into its modern form in 1907.[86] By then it was possible for one piece of switching equipment to route large numbers of calls, creating scale efficiencies.

Telecommunications providers deployed automatic switching systems over three decades during which local telecommunications markets went from monopoly to limited competition and back again. When the original Bell patents for telephone service expired in 1893–1894, about 60 independent companies were offering service.[87] By 1907, with the onset of automatic switches, there were more than 5,000 independent carriers, and they oper-

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[81] See *FCC Long-Distance Report*, 1999 FCC Lexis 1351, *7 (table showing AT&T's share of interstate minutes in 1988-89).

[82] An automatic exchange is "[a] term for a central office which automatically and electronically switches calls between subscribers without using an operator." *Newton's Telecom Dictionary* at 83 (cited in note 65).

[83] In this case, automation refers only to automating local calls. See Joel and Schindler, *Switching Technology* at 7 (cited in note 48).

[84] Dodd, *Essential Guide to Telecommunications* at 30 (cited in note 49).

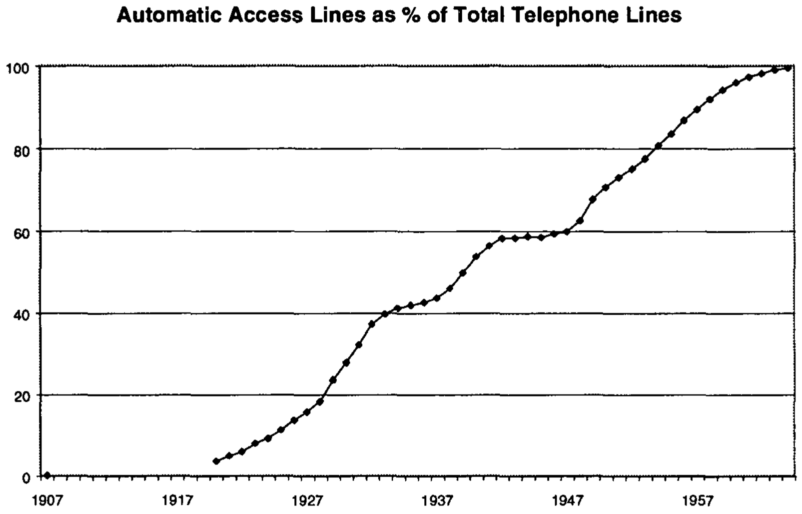
[85] Robert J. Chapuis, *100 Years of Telephone Switching (1878–1978) Part 1: Manual and Electromechanical Switching (1878–1960s)* 61 (North-Holland 1982).

[86] Id at 67. Group selection, dial-pulsing, the line-finder, and central battery power supply were not all used in systems until 1907.

[87] M.D. Fagen, ed, *A History of Engineering and Science in the Bell System: The Early Years (1875-1925)* 551 (Bell Telephone Laboratories 1975).

ated about 45 percent of the nation's telephone lines.[88] At first, the new entrants focused on markets the Bell system had ignored—smaller towns and rural areas. Figures are not available on the extent of actual head-to-head competition, but at least in some large cities, consumers could choose between two or perhaps even more local providers.[89] Shortly after losing its original patent-based dominance, however, the Bell System began reacquiring its lost market share by refusing to interconnect independents to its local networks or to its superior long-distance network. Bell soon began acquiring independents and swapping service areas so that there was only one provider in any given area.[90] By the time automatic switching reached 30 percent of the market, the Bell System served 80 percent of all lines[91] and there was virtually no head-to-head competition (Figure 8).

Figure 8: Automatic Switching



On the technology-production side, AT&T's subsidiary, Western Electric, manufactured almost all customer-end and central office equipment used in the Bell system, from handsets to

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[88] Id.

[89] See generally Robert Noll and Bruce Owen, *Anticompetitive Uses of Regulation,* in John E. Kwoka, Jr. and Lawrence J. White, eds, *The Antitrust Revolution,* (Scott, Foresman 1989).

[90] Gerald W. Brock, *The Telecommunications Industry: The Dynamics of Market Structure* 65 (Harvard 1981).

[91] Noll & Owen, *Anticompetitive Uses of Regulation* (cited in note 89).

switches.[92] In 1916, Western Electric acquired the manufacturing rights for automatic-switching equipment.[93] Early on, the Automatic Electric Company made equipment to Bell system specifications and, beginning in 1926, Western Electric began manufacturing this equipment as well.[94] Throughout this time, other manufacturers, such as the North Electric Company, were also producing automatic switching systems, though they enjoyed only limited success (Western Electric also purchased manufacturing rights to the North Electric system in 1916.)[95] The technology-production side of the market was thus not as concentrated as it was for some of the other innovations discussed in this study but was nonetheless not highly competitive.

3. Deployment under competitive oligopoly conditions.

Although none of the innovations in this study's sample were deployed in a market that contained a large number of competing firms, three of the cases involve markets that had more than three competitors. Those technology cases are digital subscriber line telephone transmission, cable modem service, and digital wireless transmission. As with the technologies implemented under monopoly and concentrated oligopoly conditions, those implemented under comparatively competitive oligopoly conditions vary in their deployment times. In this sample, the time it took for the innovation to be deployed in 30 percent of the relevant network points ranged from two years for DSL capability, to three years for cable modem service, to seven years for wireless digitization.

a) Digital Subscriber Line service. DSL technology[96] uses sophisticated compression techniques to increase the data carrying capacity of existing copper wires. By placing a modem at the carrier's central office and another at the customer's premises, DSL provides customers an "always-on" connection to the inter-

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[92] AT&T/Bell did operate equipment from Automatic Electric in systems it had acquired from Independents. By 1915, Bell operated Automatic Electric equipment served some 90,000 lines. Fagen, *Early Years* at 554 (cited in note 87).

[93] Id.

[94] Id.

[95] Id.

[96] DSL technology "uses existing copper wires from the telephone company central office to the subscriber's premises, involves electronic equipment in the form of ADSL modems at both the central office and the subscriber's premises, sends high-speed digital signals up and down those copper wires." *Newton's Telecom Dictionary* at 41 (cited in note 65).

net at speeds of up to 8 megabytes-per-second ("Mbps")—far faster than the maximum 56 kilobytes-per-second ("Kbps") achievable over the same lines with conventional modems. Bellcore, now Telcordia, developed DSL in 1989 as a way to deliver video signals to users from central offices over telephone lines.[97] Although telephone companies did not initially use DSL technology for video or any other consumer offering, they did use DSL for internal purposes and to improve the operation of their networks. For example, certain DSL technologies eliminated a substantial amount of the work ("cleaning" lines to customers and installing repeaters to maintain transmission speed) necessary to provide high-speed "T1" data service to business customers. The local Bell companies thus used DSL as an input for the provision of faster and more expensive data services.[98]

Carriers did not offer DSL service as a consumer product on its own until late in 1996. That year, the Telecommunications Act of 1996 ("the Act") opened the local telephone market to competition. The Act required incumbent telephone companies to lease out elements of their systems for competitors to use to provide service.[99] New entrants were then able to lease copper "loops" that link central offices to customers, install their own DSL equipment and connections to the internet, and offer high-speed data service to customers that was cheaper and easier to obtain than T1 service.

An internet service provider and an incumbent local telephone carrier in Alaska were the first to offer DSL to consumers, towards the end of 1996.[100] Since then, numerous competing carriers have entered the market for high-speed data services by offering DSL to business and residential customers. Incumbent carriers began wide-scale commercial deployment of DSL in 1998.[101]

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[97] Dodd, *Essential Guide to Telecommunications* at 152 (cited in note 49).

[98] Carl Liebold, *Telcos Look to Enter Homes via DSL*, Electronic Engineering Times, (Mar 4, 1996).

[99] 47 USC § 251(c)(3) (2000).

[100] David Kopf, *Striking While the Copper is HOT*, America's Network 8 (Nov 15, 1996) <http://www.americasnetwork.com/issues/96issues/961115/111596-adslpro.html> (visited Sept 19, 2000); ADSL Forum, 1998. *ADSL Service Deployments*, <http://www.adsl.com/service_matrix.html> (visited Aug 1999).

[101] Analyst reports and Telechoice, *Deployment Update*, <http://www.xdsl.com/content/resources/deployment_info.asp> (visited Nov 9, 1999) (Data is the proportion of RBOC lines that could be served by xDSL).

DSL faces a variety of technical hurdles, including limits related to the length and physical condition of customer lines.[102] The DSL market nonetheless became hotly contested early on, with numerous entrants as well as providers of alternative technologies like cable modem service (see below) competing for broadband customers. It took only three years from the first commercial deployment of DSL for the technology to reach 30 percent of telephone company central offices.[103] Although the actual number of lines served is only a tiny fraction of the total served by any central office, the number of subscribers is growing rapidly and the capability is in place for carriers to serve the rising demand.

b) Cable modem service. Cable modem[104] service provides consumers with high-speed data access through the cable television system. The service thus competes to a large degree, though over a distinct physical network, with DSL service. To offer cable modem capability, cable operators must first enable their networks to provide sufficient two-way capability for customers to send as well as receive data. Operators must in addition install equipment at the cable office (the cable "head end") that can receive data from subscribers as well as transmit data and programming to them. Furthermore, these upgraded systems must be supported and connected to content by building an IP networking infrastructure that interconnects with the internet backbone.[105] With these changes, conventional cable systems can provide high-speed internet access over one or more of their channels. Cable modems were first tested around the country at the end of 1993,[106] but were not offered commercially until 1995.[107]

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[102] See *In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable And Timely Fashion*, 2000 FCC Lexis 4411, *287; Howard A. Shelanski, *The Speed Gap: Broadband Infrastructure and Electronic Commerce*, 14 Berkeley Tech L J 721, 727 (1999).

[103] In 1999 there were 22,154 total central offices, and by the end of 1999, private data sources reported that carriers have deployed DSL in 6,897 of those offices. See FCC, 1999. *Trends in Telephone Service*, CCB/IAD, Table 6.1 (depicting the number of central offices) (cited in note 52); *Q4 1999 TeleChoice DSL Deployment Summary*, <http://www.xdsl.com/content/resources/deployment_info.asp> (visited Oct 5, 2000) (depicting the rate of DSL deployment).

[104] "[A] cable modem is a modem designed for use on a TV coaxial cable circuit." *Newton's Telecom Dictionary* at 134 (cited in note 65).

[105] This includes backbone connectivity to the internet, and the routers, servers, and network management tools to enable communications across the network.

[106] Jones Intercable was the first cable company to start testing when it offered, on a limited basis, service to Alexandria, Virginia in December 1993. See Kent Gibbons, *Cable TV to Carry Internet to Alexandrians*, Washington Times B9 (Sept 30, 1993). Several other

Since then, cable operators have been rapidly upgrading their systems to support high-capacity, two-way transmissions; over 30 percent of cable homes were offered cable modem service by 1999.[108]

c) Digital wireless transmission. The first wireless telephone systems built in the United States used analog transmission technology. In the early 1990s, some wireless operators began instead to use digital transmission of conversations (as a series of on and off pulses) as opposed to analog signals. The conversion to digital technology enabled wireless providers to carry vastly more traffic than they could over analog systems with the same amount of spectrum. Depending on the technology used, digital cellular offers three to ten times the capacity of analog service over the same bandwidth.[109] It also enables calls of higher sound quality, and other new services such as caller id, paging, and messaging. The conversion of analog systems to digital started in Chicago and Los Angeles in 1992-93.[110]

When the FCC initially distributed cellular licenses in 1984, one license for each market was given to the incumbent local telephone company and the other was allocated through a lottery to a competitor. In 1992, the FCC published a rollout plan for allocating additional spectrum for a new set of digital wireless telephone services called Personal Communications Services ("PCS") which would compete with existing cellular services.[111] Congress mandated that the FCC auction licenses for the new spectrum starting in 1994.[112] Competition increased quickly after the auctions. In the last quarter of 1999, nearly all Americans (94 percent) could choose among three or more wireless providers, and

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cable companies followed closely thereafter, with Comcast, Viacom, Continental Cablevision, Cox Cable Communications, and Times Mirror Cable all announcing pending tests that same month. See Clark, *Tests Linking PCs, Cable TV Lines to be Slated By Several Big Firms*, Wall St J B8 (Dec 1, 1993).

[107] See John Borland and Corey Grice, *The Next Wave in Fast Net Access*, CNET News.Com, July 28, 1999, available online at <http://www.news.com/SpecialFeatures/0.5,38002,00.html> (visited July 28, 1999).

[108] See Kinetic Strategies, *Cable Modem Market Stats & Projections*, Nov 9, 1999, <http://www.cabledatacomnews.com/cmic/cmic16.html> (visited Nov 9, 1999).

[109] Dodd, *Essential Guide to Telecommunications* at 218 (cited in note 49).

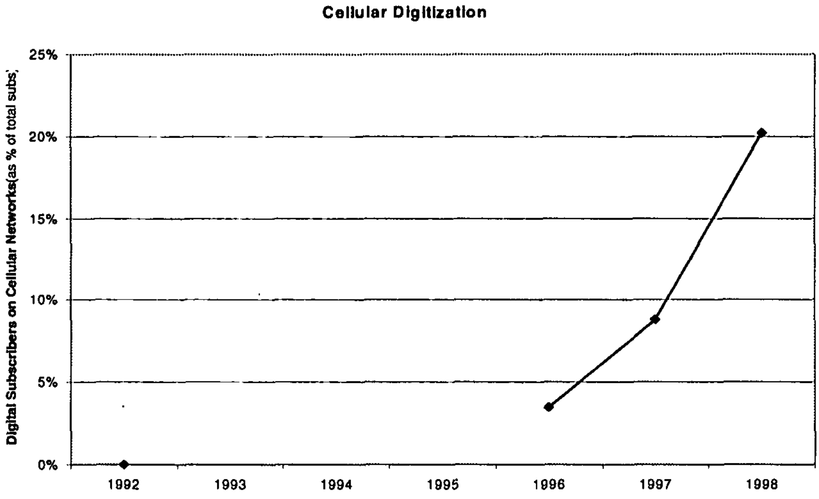
[110] Denise Gellene, *Digital Stirs Into the Cellular Stew Technology*, LA Times 1 (Nov 26, 1993).

[111] *In the Matter of Redevelopment of 220 Mhz of Spectrum in the 1.85 to 2.20 GHz Band*, 7 FCC Rec 6886 (1992).

[112] 1994 Pub L No 103-66, 107 Stat 312.

75 percent had a choice of five or more carriers.[113] There are now, on average, more than two PCS providers competing against the two original cellular licensees in each geographical market. By 1998, about 30 percent of wireless subscribers in the United States were on digital systems (Figure 9).[114] The wireless sector was thus quite competitive during the early deployment period for digital wireless service. The market for the network equipment necessary to provide digital wireless service has also been comparatively competitive, with producers such as Nokia, Lucent, Ericsson, and Motorola vying for share.

Figure 9: Digital Subscribers on Cellular Networks[115]



B. Analysis of the Data on Deployment and Market Structure

The above case studies reveal that there have historically been greatly varying deployment rates for important, innovative telecommunications technologies. The comparisons are certainly imperfect. The sample technologies differ in their costs of deployment, the parts of the network relevant to measuring their adoption and implementation, the benefits they confer on telecommunications carriers and customers, how they are affected by

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[113] See William E. Kennard, *Telecommunications @ the Millennium; The Telecom Act at Four* (Feb 8, 2000*)*, 2000 WL 140542.

[114] *Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services: Fourth Report*, Appendix B, Table 5, FCC Rec 10145 (1999).

[115] Data is the number of digital cellular subscribers over total subscribers for cellular license holders. Id.

regulation, and other variables. Those factors should all be taken into account in a complete analysis of telecommunications market structure and innovation. But for the purposes of this paper—developing a preliminary presumption for policymakers about the relationship between competition and innovation in U.S. telecommunications markets—the comparisons provide a useful benchmark, particularly in light of the systematic correlation in the data, discussed in more detail below.

The time for the sample of technologies discussed above to reach a 30 percent deployment level ranged from two years for DSL to fourteen years for electronic stored-program-control switching. The market structures in which the firms deploying the technologies operated range from pure monopoly in the cases of touch tone, digital switching, and ISDN; to duopoly or triopoly for SS-7 signaling, fiber optics, and automatic switching; to competition among several firms in the cases of digital wireless, DSL, and cable modem service.

When deployment times and market structures are matched, faster deployment times correlate with more competitive markets. Figure 10 plots deployment times against market structure, taking into account the market structures for both the technology-producing firms and the technology-deploying firms. While there is substantial variation in deployment times for different technologies under a given market structure—from four to fourteen years under monopoly, four to twelve years under duopoly/triopoly, and two to seven years under competition—average deployment times speed up as markets become more competitive.

The correlation presented below is, of course, a rough measure. A more useful analysis might compare how deployment rates for a given technology change as market structures change. That counterfactual exercise is difficult to perform, however, because in most cases market structure did not vary for a given technology during the relevant period. A couple of cases do, nonetheless, provide insight into the effects of competition on the speed of deployment.

Figure 10: Average Time (Years) from 1st Adoption to 30% Penetration

Market Structure of Firms Deploying Innovation

Market Structure of Technology Producers

	Competitive		Monopolistic	Avg.
Competitive	DSL: 3 Cable Modems: 3 Cell. Digitization: 7 Average: 4.3	Fiber Optics: 6	ISDN: 9	5
		SS-7: 4 Automatic Switching: 12 Average: 8	Digital SPC: 7	8
Monopolistic			Electronic SPC: 14 Touch-Tone: 4 Average: 9	9
Avg.	4	7	9	

In the case of DSL, the technology was not deployed at all to provide retail, high-speed data services when local exchange companies had regional monopolies. Part of the reason DSL was not offered may be that there was little demand for DSL before mass use of the internet began in the early to mid 1990s. But the implementation of ISDN, and the fact that DSL stayed off the market even after internet use began to soar, suggests that other, strategic considerations may have played a role in the incumbents' roll-out decisions. Indeed, only after Congress passed the 1996 Act and competition for data customers ensued did incumbents initiate commercial DSL offerings.

The second example, fiber optic technology, was available and proven in a commercial telephone network in 1977. But only in the mid-1980s, after the opening of the long-distance market to competition and Sprint began touting its fiber-optic facilities, did deployment accelerate. Again, the decision not to use fiber might at first have been perfectly efficient; if the condition of existing plant and demand conditions did not warrant rapid replacement of long-distance infrastructure, rapid fiber deployment should not have been expected. But as competition drove prices down, increased call volume, and raised quality standards, carriers perceived fiber as a competitive necessity. In other cases examined in this study, unfortunately, similar comparisons of deployment of a given technology under varying market conditions are not possible.

Another limitation of the simple correlation between market structure and technological change is that it does not provide information about causality. There is no way to tell, without substantial additional analysis, whether market structure was significant in speeding deployment or whether other variables—return on investment or regulatory factors, for example—are responsible for the variation in the sample. But the purpose of this study is not to provide a full explanation for the rate of technological change in the industry. The goal is the much more modest one of examining whether market competition has, on its face, been either consistent or in tension with rapid deployment of new telecommunications technology. What the positive correlation between deployment and competitiveness tells policymakers is that innovations in U.S. telecommunications have, across a varied sample of technologies, implemented more quickly in competitive than in non-competitive markets. Moreover, while there are cases, such as touch-tone dialing, where deployment has occurred quickly under monopoly, there is no case in which competition appears to have slowed deployment. Again, that conclusion cannot be definitively reached from the data in this study, but the data do provide sufficient support for an initial presumption that competition and implementation of new technology are mutually reinforcing, rather than conflicting, objectives.

CONCLUSION

Regulation and antitrust enforcement in technologically dynamic markets are challenging tasks. Enforcement that impedes technological change may have substantial social costs over time. But enforcement that is overly diffident might yield concentrated markets, higher prices, and no offsetting, long-term benefits. How policy officials should approach conflicting claims about competition and innovation is one of the central questions in U.S. microeconomic policy today. In many cases, there will not be any tension between these two objectives. In some, less frequent, cases, tradeoffs between competition and technological change will exist and the error costs of enforcement will be potentially large. This article addresses how regulators and enforcement agencies should approach claims that such tradeoffs exist in the U.S. telecommunications industry.

This Article concludes from its examination of historical case studies of technological deployment that telecommunications regulators and policymakers in the United States should approach claims that new products and services will flow from market consolidation warily. They must certainly recognize that technological innovation and conventional competitive ideals might at times conflict in as dynamic an industry as telecommunications. But their presumption should be in favor of preserving competition, and the burden of persuasion should rest with those arguing otherwise.