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The Drivers of the Information Revolution—Cost, Computing Power, and Convergence

Powerful forces are recasting the business world in a fleeter, more competitive form. These forces, largely grouped around information infrastructure and new communications technologies, have come to be known collectively as the information revolution. This Note is the first in a series of five that looks at the information revolution and the future of telecommunications—and what they mean for the regulatory role of government.

In the past few years, there has been a technological phase-shift as computers have become ubiquitous, communications technologies have multiplied, and the Internet has become a widely used means of doing business. The three most powerful trends driving these developments are the decline in the cost of transmitting information, the increase in the power of computing, and the shift from analog to digital information technologies that has joined the telecommunications and computing industries and merged market segments of the information industry. This Note explains these three trends.

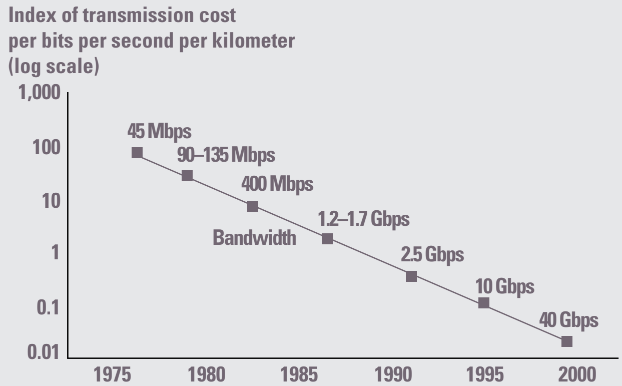
Cost of communicating

The cost of communicating has declined dramatically in the past twenty years. The cost of a voice transmission circuit, for example, has fallen by a factor of 10,000 as a result of the development of fiber optics, cheap electronics, and smart wireless (figure 1).

Fiber optics. First produced commercially by Corning Glass in 1970, fiber-optic cable has become the increasingly dominant means of signal transmission in telephony since the mid-1980s, replacing copper cables, microwave transmission, and satellite. Optical fiber has extremely high capacity (bandwidth) because of the light it transports. The high frequency of light allows higher information density than conventional cable: a fiber thinner than a single hair can carry a laser signal combining many thousands of telephone conversations, so that the cost per voice circuit becomes almost infinitesimal. Because fiber optics reduces the cost of signal transmission so much, and because this cost is increasingly fixed (with maintenance costs much lower than for conventional cable, the cost is mostly in installation), the generalization of fiber optics is profoundly changing the industry's cost structure, moving it away from existing tariff-setting mechanisms.

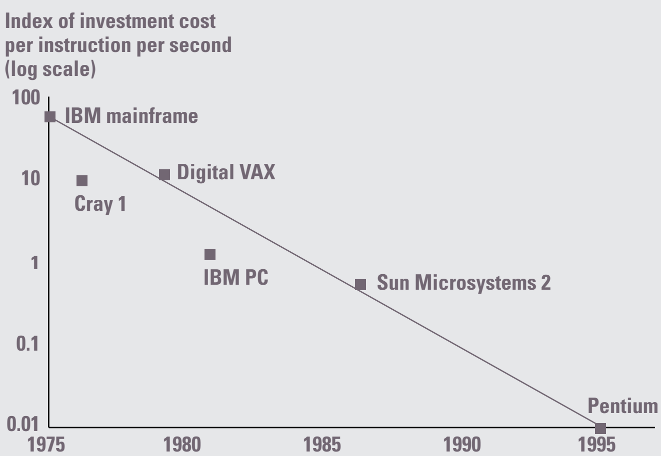
Cheap electronics. A key part of the telephone infrastructure is network exchanges, made up of switching equipment. Automatic switches were originally electromechanical, but the switches installed today are electronic—essentially specialized computers. The advent of cheap, powerful, microprocessor-based computing has altered the economics of switching, reducing costs and increasing reliability while also delivering new value added services for the user (such as call waiting and caller ID). Cheap electronics are also at the heart of cellular telephony and personal communications services, which use electromagnetic spectrum more efficiently than conventional wireless. And computing power now makes it possible to run existing telecommunications infrastructure as an "intelligent network," improving capacity utilization, lowering the cost of maintaining switches, and creating new services, such as virtual private networks.

FIGURE 1 COST TRENDS IN OPTICAL FIBER TRANSMISSION



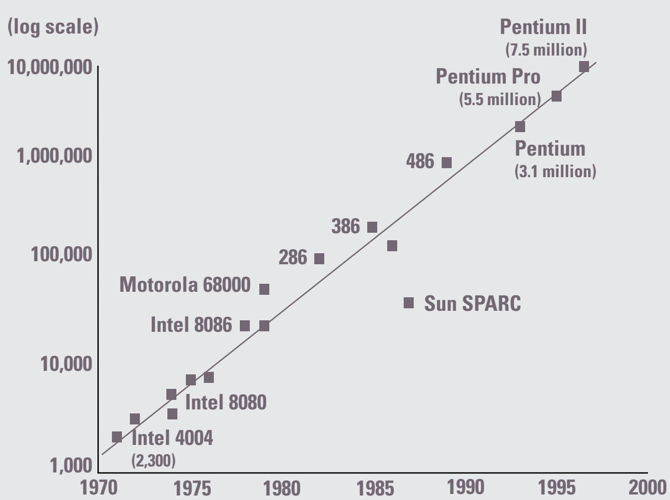
Note: Mbps is megabits per second; *Gbps* is gigabits per second.
Source: AT&T data.

FIGURE 2 PRICE TRENDS IN INFORMATION PROCESSING



Source: World Bank compilation based on industry data.

FIGURE 3 TRENDS IN TRANSISTORS PER MICROPROCESSOR



Source: World Bank compilation based on industry data.

Smart wireless. Wireless technology is evolving toward higher frequencies (inherently more information dense), with a range of clever compression algorithms to squeeze many conversations into a given frequency (such as Time Division Multiple Access, or TDMA, and Code Division Multiple Access, or CDMA). This development, coupled with cheap electronics, permits mobility for the user—in some situations, wireless has become an alternative to conventional wireline technology for basic services. Cellular telephony is growing rapidly, more than doubling worldwide every two years, while fixed wireless is increasingly being deployed for the "local loop," or local access network—that part of the network providing access to the end user. So, besides bringing overall costs down, fixed wireless has also introduced real opportunities for competing providers of local services, an area earlier deemed to be a natural monopoly. Finally, the cost of deploying wireless is much less sensitive to subscriber density (the number of customers in a given area) than that of installing wireline, so wireless is of great interest to developing countries, particularly for rural areas.

These three developments have necessarily been accompanied by a move away from analog to digital technology, in which signals are transmitted as binary code. Digital telephone networks ensure better quality and allow the use of packing protocols for data transmission, such as frame relay, Asynchronous Transfer Mode (ATM), and the Internet protocol TCP/IP.

Power of computing

The second important driver of the information revolution has been the relentless increase in the power of computing. Computing power per dollar invested has risen by a factor of 10,000 in twenty years (figure 2). Power has increased and costs have fallen because of the development of integrated circuits and microchips, because of increasing transistor density on microchips, and because of economies of scale in production.

Integrated circuits, miniaturization, and microchips. The modern electronics era began with the invention of the integrated circuit in a Texas Instruments laboratory in Dallas in 1958. The integrated circuit, which groups transistors and other electronic circuits on a tiny piece of semiconductor, is a breakthrough in product design because of its enormous potential for miniaturization and for reducing unit costs. The microchip, essentially an entire computer on a chip, was developed by Intel (as the four-bit 4004 processor) in 1971. Its 2,300 transistors provide all the essential functions of a computer.

Increasing transistor density. The density of transistors has been rising exponentially—a phenomenon sometimes characterized as Moore's law. In the 1960s, Gordon Moore, an electrical engineer and a cofounder of Intel, observed that the number of transistors on a microchip doubles every one to two years. Because computing power is roughly proportional to the number of transistors, or "gates," on the microprocessor, this would translate into a doubling of computing power per microchip every eighteen months or so. And because the cost of a microchip rises only slowly from one generation to the next and represents only about 5 to 15 percent of the cost of the computer, Moore's law would translate into a near doubling of computing power for a given investment every eighteen months. In fact, the growth in power over twenty-four years—from the Intel 4004 (2,300 transistors) of 1971 to the Pentium II (7.5 million) of 1997—averaged nearly 40 percent a year, corresponding to a doubling every twenty-five and a half months—close enough to Moore's estimate (figure 3).

Economies of scale. Computing has also become far cheaper and more powerful because of economies of scale in production, not only of microchips but of such essential ancillary equipment as mass storage (disk drives), removable storage, and computer network equipment. The emergence of a set of de facto industry standards—based on the first IBM personal computer (PC) of 1981, the Intel microprocessor instruction set, and the Microsoft operating systems (DOS and Windows)—has also enabled producers to standardize equipment and software and encouraged price competition.

One result of the increase in the power of computing and the decline in the cost of communicating is the rise of networks. When PCs began penetrating the business environment around 1981, they were used mainly as stand-alone workstations. Independent mainframe computers, accessed by "dumb" terminals, continued to handle much of the heavy processing. Today's business computers are connected to one another in local area networks (LANs), and increasingly, these private networks are interconnected through the Internet, the international "network of networks," which is doubling in size every year. Because of the growing interconnection, PCs' primary function has shifted from document and spreadsheet management to communication and information processing. The growth of the Internet illustrates Metcalfe's law (Metcalfe was the cofounder of modern computer networking), which states that the value of a network equals the square of the number of interconnected nodes. As new users join the Internet, its value for all users increases geometrically. Metcalfe's law illustrates how networking PCs radically increases their value as a knowledge tool.

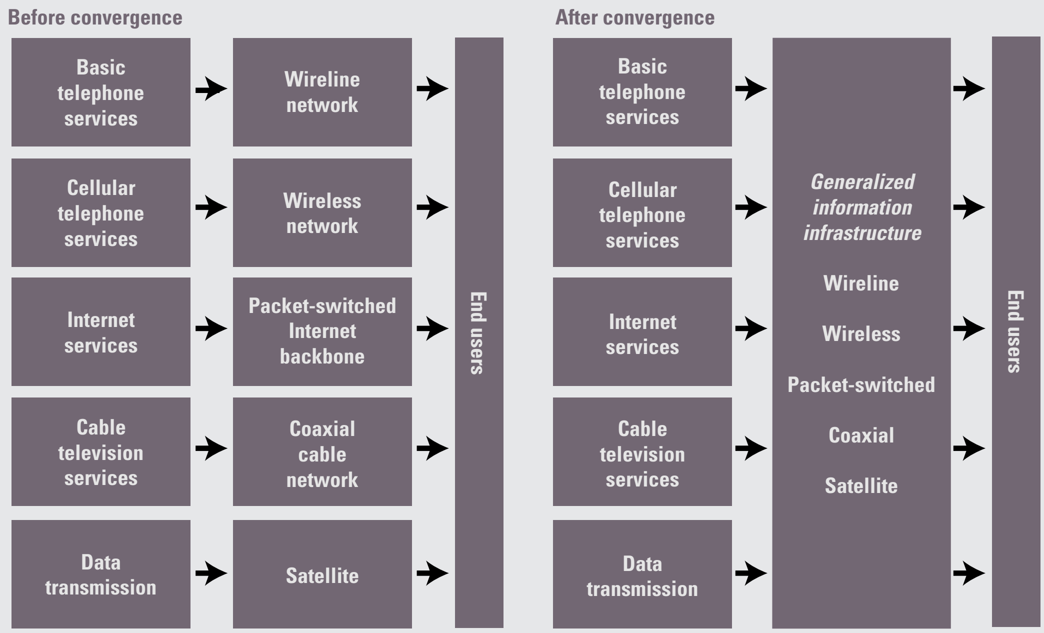
Convergence

As costs have fallen and digitalization has replaced analog technologies in telecommunications, the telecommunications, information technology, and media industries are merging into a "bit industry" that manipulates voice, image, video, and computer data in binary form. This convergence has profound implications for the industries involved.

- Communications and information services are being delinked from their underlying delivery infrastructure: telephone services can be delivered through coaxial cable, data services and Internet access through telephone lines, and cable TV through direct broadcast satellite.
- Accompanying the delinking is increasing overlap between the two primary components of the communications industry, which have traditionally been segregated: common carrier conduit systems and networks designed to transmit signals anonymously (telephony) and content-based information sources and technologies (broadcasting).

Thus, it is now possible to receive radio broadcasts over the Internet (using telephone net-

FIGURE 4 THE CHANGING INFORMATION INFRASTRUCTURE UNDER CONVERGENCE



works), and telephone services can be provided by companies in cable TV (a broadcasting medium). Broadcasting (from one to many) now shades from narrow-casting (custom-tailored information) to one-to-one communication like telephony (figure 4).

Convergence has important implications for policymakers. First, it has made existing models for the telecommunications industry obsolete. Those models have assumed that telecommunications is a public service, delivered through a network that is a natural monopoly. But these models are negated by the competition now possible between segments of the delivery infrastructure (intermodal competition) and, increasingly, within segments (intramodal competition). Convergence thus means that governments must lower barriers to entry and overhaul telecommunications regulatory systems to promote competition, moving away from utility-type regulation (Viewpoint 121).

Second, convergence raises serious issues relating to content regulation. In broadcasting, countries have applied standards of decency, privacy, and protection of intellectual property rights using different mechanisms, but usually relying on a combination of self-regulation and legal sanctions (through the courts). Telecommunications content has been largely unregulated, because it is not technically possible to do so using existing content regulation mechanisms. And convergence opens new realms of communications where traditional content regulation cannot be applied. In this context, what do policymakers do about decency, privacy, and intellectual property rights?

Convergence also opens up huge opportunities for developing countries to accelerate the rollout of connectivity to their populations using innovative technologies and private sector–led investment in a competitive mode. Cheaper communications are offering new possibilities for countries to be internationally competitive and to "plug in" to the global economy—and providing much more cost-effective ways to deliver essential public services to the poor.

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