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SOCIETY and TECHNOLOGICAL CHANGE

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part one

Orientations

The ability to create and use a great variety of technologies is one of the distinguishing characteristics of humans, but what exactly is meant by "technology"? The term is a familiar one, but like many words in current circulation it carries with it a multitude of meanings. Chapter 1 offers a definition of technology that is meant to be precise but elastic enough to cover the many connotations of the word. Although technology is often associated with particular items of hardware, the ultimate basis of technology is knowledge, and the chapter delineates the ways of thinking that are associated with technological advance.

Chapter 1 also includes an effort to disentangle technological advance from an even more slippery concept: "progress." In Chapter 2 the discussion is continued by noting that many technological changes do not necessarily make things better for everyone, as is implied in the word "progress." To the contrary, they may affect individuals and groups in different ways, leaving some better off while others are left in a worse position. This aspect of technological change is often ignored, making it hard to resist the temptation to seek technological fixes for problems that require more than the introduction of new devices and processes. This chapter describes the kinds of situations where technological fixes are likely to be successful and others where they are doomed to failure.

chapter one

The Nature of Technology

Today's technology leaves us both exhilarated and terrified. Recent technological developments have presented us with such marvels as spacecraft leaving the solar system, instant access to billions of Internet Web pages, and diseases cured through gene therapy. At the same time, however, the seemingly inexorable march of technology has produced global pollution, overpopulation, and the threat of nuclear annihilation. On many occasions technological change has also produced social disruptions, as when automation destroys jobs in a particular industry or a new weapon upsets the balance of power between nations. And when technologies fail, some of them do so in a big way, as exemplified by the loss of the *Challenger* and *Columbia* space shuttles, the massive oil spill in the Gulf of Mexico, the catastrophic failure of the Fukushima nuclear plant in Japan, and the disastrous breaching of the levees in New Orleans in the wake of Hurricane Katrina.

Despite all the crises, disruptions, and disasters that have accompanied it, modern technology is still viewed in a favorable light, according to public opinion surveys. Although significant minorities of respondents express their disapproval of certain technologies like nuclear power and genetically modified foods, the positive achievements of technology as a whole are seen to substantially outweigh the negative ones.[1] But this support of technology is based more on faith than on understanding. When confronting technology, most of us are poorly informed spectators, seemingly incapable of understanding an esoteric realm of lasers, microprocessors, gene splicing, and nanomaterials.

This inability to understand technology and perceive its effects on our society and on ourselves is one of the greatest, if most subtle, problems of an age that has been so heavily influenced by technological change.[2] But ignorance need not be a permanent condition. Although no one can hope to comprehend the inner workings of even a small number of the most significant technologies, it is still possible to come to a better understanding of the major causes and consequences of technological change. All technologies, be they high-definition televisions or reinforced concrete bridges, have some basic features in common. It will be the task of this chapter to show what they are.

Defining Technology

Gaining an understanding of the meaning of words is often the beginning of knowledge. Before plunging into a discussion of the nature of technology, it is necessary to provide a more precise definition of what is meant when we use the term. The linguistic roots of the word "technology" can be traced to the Indo-European stem *tekhn-*, which seems to have referred to woodworking. It is the source of the Greek word *tekne*, which can be variously translated as "art," "craft," or "skill." It is also the root of the Latin word *texere*, "to weave," which eventually took on the larger meaning of fabrication or construction. The term "technologist" was occasionally used by Aristotle and others of his time, but in their usage it referred to a grammarian or rhetorician. By the early eighteenth century the word had come close to its present meaning when an English dictionary defined it as "a Description of Arts, especially the Mechanical." In 1831 Jacob Bigelow published *Elements of Technology*, the first book in English with the word "technology" in its title. As he defined it, technology consisted of "the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science."[3]

Technologies are developed and applied so that we can do things not otherwise possible, or so that we can do them cheaper, faster, and more easily. The capacity of human beings to employ technologies sets us apart from other creatures. To be sure, beavers build dams, otters crack open shellfish with rocks, and chimpanzees use sticks to extract termites from their nests. But no other animal comes close to humans in the ability to create tools and techniques—the first two elements in our definition of technology—and no other creature is so dependent on them. The development of technology is in large measure responsible for the survival and expansion of a species that lacks many of the innate abilities of other animals. Left with only their innate physical capabilities, humans cannot match the speed of a cheetah, the strength of an elephant, or the leaping ability of a kangaroo. They do not possess the eyesight of an eagle or the defensive armament of a porcupine, and they are among the 25 percent of all species that are incapable of flying. All in all, humankind is a physically puny bunch. But compensating for this physical weakness is an intelligence that is the ultimate source of technology. Humans stand apart from all other animals in their ability to gain and transmit knowledge, and to use this knowledge to develop tools and techniques. Without this capacity to invent and use a great variety of technologies, members of the human species would have never been able to establish themselves on virtually every part of the globe.

Reliance on technology is as old as humanity itself. Whatever evils have accompanied the use of particular technologies, it is pointless to indict technology as being somehow "unnatural." Our past as well as our future as a species is inextricably linked to our capacity to shape our existence through the invention and application of implements and techniques that allow us to transcend our meager physical endowments. It is certainly true, as Jacob Bronowski observed, that "to quarrel with technology is to quarrel with the nature of man—just as if we were to quarrel with his upright gait, his symbolic imagination, his faculty for speech, or his unusual sexual posture and appetite."[4]

Tools and techniques have been of unquestioned importance in allowing the physical survival of the human species. Still, they are not the whole story.

It is necessary to add some elements to our definition of technology that go beyond the usual identification of technology with pieces of hardware and ways of manipulating them. The first of these is *organization*. This follows from the fact that the development, production, and employment of particular technologies require a group effort. Even a relatively simple technology, such as one centering on the use of earthenware pots, requires a complex network of material suppliers, potters, tool makers, marketing agents, and consumers capable of making good use of the pots. Of course, one person can learn all these skills adequately if not expertly, but the day is not long enough for him or her to do them all on a scale that produces a reasonable degree of efficiency. In the case of a complex technology like a computerized manufacturing system, there is no possibility of a single individual developing even a tiny fraction of the requisite skills. For a technology to be developed and used, the energies and skills of many individuals have to be combined and coordinated through some organizational structure. Organization may be likened to the software that controls and guides a computer; without an operating system and application programs, a computer is a useless arrangement of capacitors, transistors, resistors, and other bits of hardware. In similar fashion, an organizational structure allows the integration of diffuse human and material inputs for the attainment of particular tasks. From this standpoint, there is considerable merit in Lewis Mumford's assertion that the first "machine" was not a physical object, but the organizational structures that the Egyptian pharaohs employed to build the pyramids.[5]

When technology is seen as a combination of devices, skills, and organizational structures, it becomes natural to think of it as a *system*, the next element in our definition. For an individual technology to operate effectively, more is required than the invention of a particular piece of hardware; it has to be supported by other elements that are systematically interconnected. When Thomas Edison began to work on electrical illumination, he realized that this technology would require the development of such a system. The invention of a practical, long-lasting light bulb rested on the development of a serviceable filament and the use of an improved vacuum pump that evacuated the interior of the bulb, thereby preventing the combustion of the filament. But by itself, a light bulb was useless. An effective electrical generator was needed to supply the current that produced the incandescence of the filament. A network of electrical lines had to be strung up between the generator and individual homes, shops, and factories. And metering devices were necessary so that users could be accurately billed for the electricity they used. Edison and his associates worked out all of these problems, and in so doing brought large-scale electrical illumination to the world.[6]

The development of all the elements of a technological system can be an uneven process, for technological advance often entails the resolution of tensions that are generated when one part of the technological system changes. This process is exemplified by the development of the modern airplane. Early biplanes with their drag-inducing wires and struts could not make effective use of more powerful engines. The availability of these engines became a strong inducement to the design of aerodynamically cleaner aircraft. The faster aircraft that resulted from the marriage of streamlined airframes and powerful engines produced a new problem:

dangerously high landing speeds. This, in turn, stimulated the invention of wing flaps and slots. By the 1940s it had become apparent that improved airframes could achieve still higher speeds if provided with more powerful engines; this possibility gave a strong stimulus to the development of the turbojet.[7]

For an example of the interplay of devices, skills, and organizational patterns, we can take note of Lewis Mumford's analysis of the technology of handwriting.[8] Two hundred years ago, the standard writing instrument was a goose-quill pen. Based on an organic product and sharpened by the user, it represented the handicraft technologies typical of its time. Cheap and crude, it called for a fair degree of skill if it was to be used effectively. In contrast, the steel-nib pen of the nineteenth century was a typical artifact of the industrial age, the product of a complex manufacturing process. Less adaptable than the quill, it was mass-produced in many different forms in order to meet specialized needs. Although Mumford's ideas were formulated before the invention of the ballpoint pen in the 1940s, his analysis fits this implement perfectly. Made from a variety of artificial materials and manufactured to close tolerances, the ballpoint pen could only be produced through sophisticated industrial processes. It is completely divorced from the organic world and requires very little skill from its user. Indeed, the technological artistry embodied in the pen itself stands in sharp contrast to the poor quality of the writing that so often comes from the hand that wields it.

A technological system does not emerge all at once with every one of its components neatly fitting together. In addition to changes in tools, techniques, and organizational structures, many social, psychological, economic, and political adjustments may be required for the support of a technological system. Technological change is not always a smooth process, and many of the necessary changes may entail considerable pain and disruption. Seeing technology as a system should help us to understand that technological change is closely connected with a variety of associated changes, and that the creation of a technological system may be fraught with tension and discomfort.

Much of what has just been said can be incorporated into a schematic definition of technology: **a system created by humans that uses knowledge and organization to produce objects and techniques for the attainment of specific goals.**

Useful as it may be, this definition of technology is incomplete and possibly misleading in one important respect. The last part of the definition implies that technological change comes about as a response to existing needs: its purpose is "the attainment of specific goals." In the first place, one could legitimately ask *whose* goals are to be attained. This is an important issue, but it is best left for the next chapter. For now, we should note that although it is a human creation, technology does not always respond to existing needs; a new technology may in fact create its own needs. The development of technology on occasion exemplifies a phenomenon that has been dubbed "the law of the hammer": give a six-year-old a hammer, and to the child everything starts looking like a nail.

The history of technology is replete with examples of inventions looking for problems to solve. One example that illustrates this point is found in almost every medicine chest: a bottle of aspirin. One of the most common uses of aspirin is to suppress fevers that accompany various illnesses. But recent medical research (as well as some ancient practices) has demonstrated that running a fever is a therapeutic process that aids in a patient's recovery; it is the body's way of naturally combating infection. Yet since the introduction of aspirin in the early 1900s, fever has been seen as a problem requiring intervention. As one medical researcher has noted, "It's no surprise that society's deep worries about fever closely followed the synthesis of aspirin, the first drug that could safely reduce it."[9] In short, a new technology created its own need.

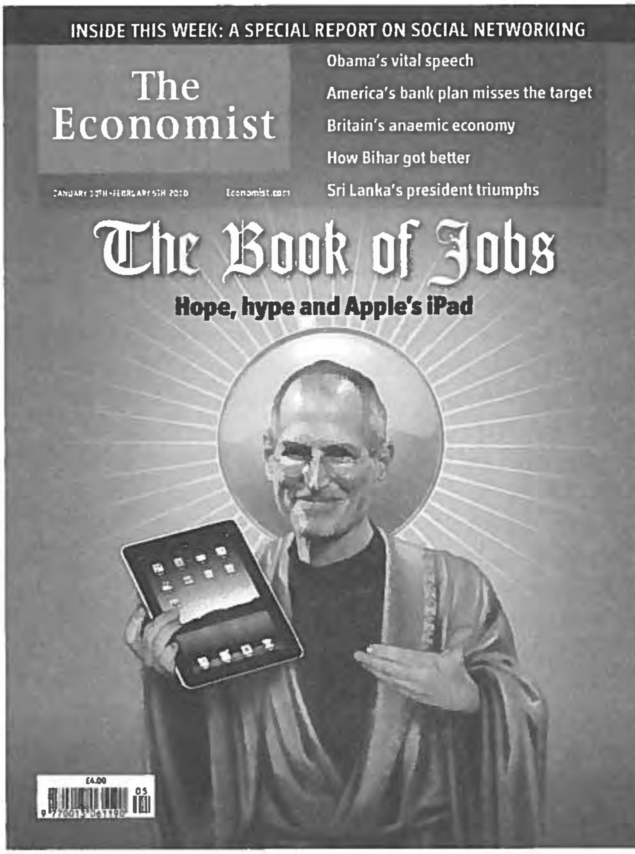
It is also important to note that the goals achieved through the use of a technology do not have to be "practical" ones. Some technologies have been developed so that we can grow more food or construct more comfortable buildings, but others have been developed simply for the challenge and enjoyment of solving technological problems,[10] a proclivity that Robert Post has described as "technological enthusiasm."[11] The prodigious efforts that went into the Daedalus Project, a successful attempt to build a human-powered aircraft capable of flying forty miles across the open sea, were certainly not motivated by an effort to produce a new form of transportation. A major reason for creating the aircraft was that its construction posed an intriguing technological challenge to those who designed, built, and flew it.

Flight seems to be a particularly attractive object for this kind of spirit. Immensely expensive technological endeavors such as the supersonic Concorde airliner and manned space exploration programs are hard to justify on practical grounds, although their supporters have made valiant efforts to do so. Their primary purpose seems to be the elevation of national prestige by demonstrating a nation's collective ability to solve daunting technological problems. At the same time, many other technologies have a dual nature; they serve a practical purpose, but they are not valued only for this reason. An outstanding example is the automobile. It would be hard to justify the enormous resources employed for the building and operation of cars if transportation were the only goal. For many people (the author included), cars are objects of inherent fascination. Technological features like variable valve timing and active suspension systems have little to do with utilitarian transportation. The appeal is at least as much in the sophisticated technologies themselves as in the purposes that they serve.

Technological Advance and the Image of Progress

The development of technology is an inherently dynamic and cumulative process. It is dynamic because a technology is never perfect; there is always room for improvement. As Henry Ford said of his firm, "If we have a tradition it is this: Everything can always be done faster and better."[12] It is cumulative, for one advance paves the way for another. The lessons learned in working with an existing technology very often provide materials, tools, and, most importantly, a knowledge base for the next stage of development.

The dynamic and cumulative nature of technological change sets it apart from many other human endeavors. Ignoring for the moment the social consequences

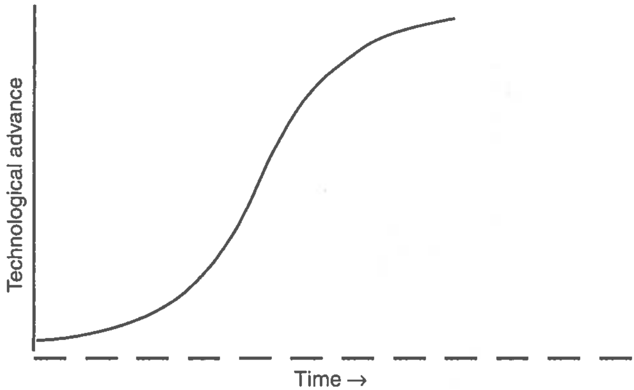


Sometimes we are inclined to look to technology for our salvation, as personified in this tongue-in-cheek rendition of a sanctified Steve Jobs. (©The Economist Newspaper Limited, London)

of technology, the process of technological change is usually one of continuous improvement in the internal workings of a particular technology: as they evolve, engines develop more power and are more efficient, integrated electronic circuits pack more components on a single chip, aircraft fly higher and faster.

The process of technological advance can be graphically portrayed according to the following diagram, in which the horizontal axis represents time and the vertical axis represents just about any aspect of technological advance: the speed of commercial airliners, the production of synthetic materials, or the number of articles in engineering journals. Although there are inevitable fits and starts over time, the general trend can be depicted as a sigmoid, or S-shaped curve:

Note that at first the curve rises rather slowly, inclines steeply in the middle, and then begins to slow down. That is, after an initial period of slow growth, the rate of advance accelerates, reaches a maximum, and then begins to proceed at a slower pace but never completely levels off. Although the rate of increase is smaller as the curve moves toward the right, this rate is applied to an increasingly larger base, so the actual addition is still substantial.



Not all human endeavors can be fitted to this sort of curve. While technology tends to be dynamic and cumulative, the same cannot always be said of other manifestations of human creativity. Although there is ample room for debate, a good case can be made that succeeding generations of writers, composers, and painters have not produced works superior to the ones created by Shakespeare, Beethoven, and Vermeer. And while we continue to take great pleasure in the artistic creations of eras long past, few of us would be satisfied with the technologies that were prevalent in those times. We also see few indications that people are more humane than they were centuries ago. The present era certainly provides a multitude of horrifying examples of human cruelty, many of them augmented by enlisting technology in the service of slaughter and destruction.

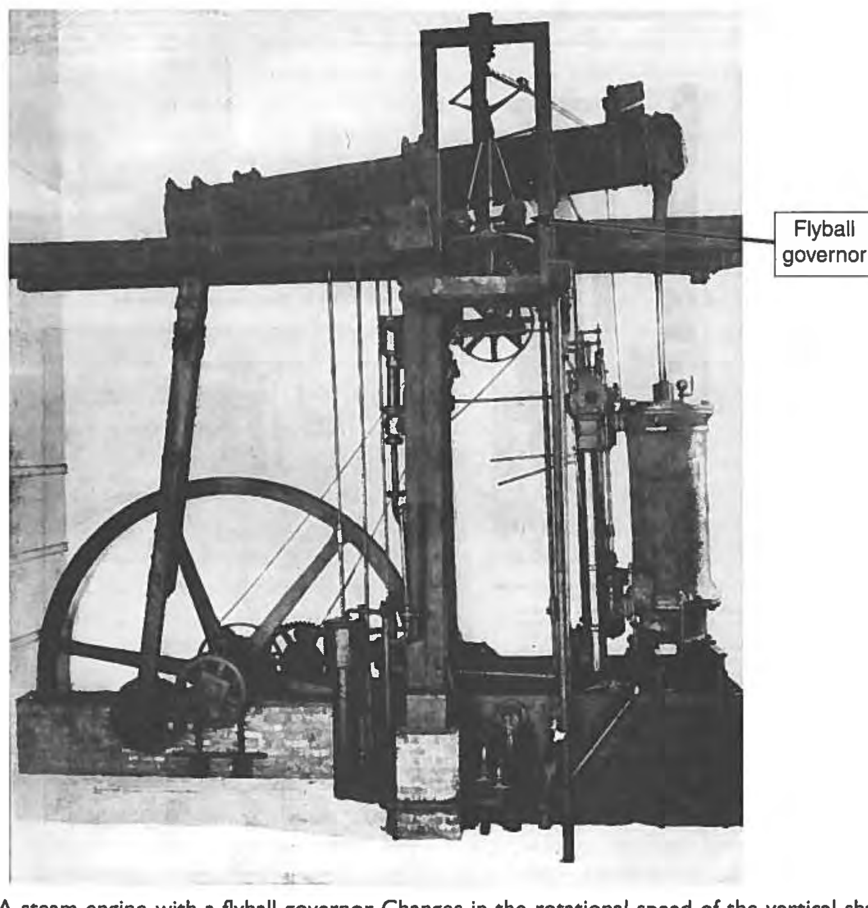
Still, when judged solely according to internal criteria, technology is one of the best examples of humankind's largely unrealized dream of continual progress. Technological progress, however, is not the same thing as progress in general. The fact that a society is able to develop and make use of advanced technologies does not guarantee that it will be equally advanced in other areas.[13] Nazi Germany produced many technological triumphs, such as the all-conquering Mercedes and Auto Union grand prix racing cars of the late 1930s and the V-2 rocket used during World War II, but in its ideology and treatment of people it can only be described as barbaric. Conversely, many technologically primitive peoples have exhibited a high level of sophistication in their artistic creations, religious beliefs, and social relationships. The term "progress" can be used with some precision when applied to the development of technology per se, although even here problems can crop up because different standards of evaluation may lead to conflicting conclusions. Is it really "progress" when a new medical technology maintains an individual's life, but does so only at enormous expense while preserving nothing but the maintenance of organic functions? Does maintaining a "life" of this sort justify expenditures that otherwise might be used for expanded prenatal care or other preventative measures? Given all of the value judgments, ambiguities, and complexities surrounding the word "progress," its use is avoided here unless its meaning is clearly defined.

Built with slave labor, the V-2 rocket exemplified the technological advances achieved in Nazi Germany. (Hulton Archive/Getty Images)

Technology as a Metaphor

Despite these qualifications, it is evident that beginning in the late eighteenth century and continuing today, technology's stunning advances have fueled a belief in generalized human progress. In this way, technology has operated as a metaphor—the transference of an idea from one area to another. Technology has provided many other metaphors that have affected our way of looking at ourselves and the world, as when human thought is made analogous to the operation of a digital computer.

A further example of the power of a technology to shape our way of thinking comes from the late eighteenth century. At that time the designers of windmills and steam engines discovered the important principle of *feedback*, which the great twentieth-century mathematician Norbert Wiener defined as "a method of controlling a system by reinserting in it the results of its past performance."[14] When a steam engine begins to rotate too rapidly, a feedback device such as a flyball governor closes the valve that admits the steam, thereby bringing the engine back into its proper operating range. When it slows down, the reverse happens, and the governor opens the valve to admit more steam.



A steam engine with a flyball governor. Changes in the rotational speed of the vertical shaft at the top of the engine causes the two balls to move up or down, controlling the linkage that opens and closes the throttle. (Hulton-Deutsch Collection/CORBIS)

During the late eighteenth century the feedback principle offered a suggestive metaphor for the workings of the economic system: instead of being guided by a centralized authority, an economy might best be organized through the operation of a self-regulating market, with the actions of independent buyers and sellers providing the feedback. Thus, when buyers wanted a particular commodity, its price would be high, motivating sellers to produce more of it. If the price were low, less would be produced. In similar fashion, an increase in production would cause the price of a commodity to fall, so more of it would be purchased, while a drop in production would cause the price to rise, leading to a reduction of purchases. In this way, the actions of buyers and sellers in the market provide a feedback mechanism through which supply and demand are supposedly brought into equilibrium. It is probably no coincidence that the Scottish economist Adam Smith developed this basic concept at the same time that the steam engine was being put into service.[15] Today, the widespread use of the feedback principle makes its apparent applicability to the economic system even more appealing, even though the real-world economy is hardly a neat closed system like a steam engine. Laws and regulations as well as a host of other extraneous elements may strongly affect individual feedback loops, thereby preventing a complex economy from operating solely on the basis of supply-and-demand signals. Technological development has supplied a useful metaphor in the feedback principle, but like all metaphors it cannot be taken as a literal depiction of reality.

Technology and Rationality

The development of technology has stimulated a belief that progress is a natural part of human life. At the same time, the progressive development of technology has itself been the product of a distinctive set of cultural values and mental processes that are characterized by a rational approach to the world and how it is to be controlled. Technological development is more than the random accumulation of tools, techniques, and organizational forms. Underlying the process is a set of attitudes and orientations that are collectively described as "rational."

What makes a technologically progressive society different from others is that its methods of problem solving are oriented toward an objective scrutiny of the problem at hand, coupled with a systematic, empirically based examination of possible solutions and a logical selection of the most appropriate ones. Beyond this approach to the solution of problems lies another cultural attribute: the belief that solutions are *possible* and that constant changes are necessary in order to realize them. A society imbued with a rational ethos is dynamic and essentially optimistic, and it exhibits the confidence necessary to alter existing ways of doing things in order to gain particular benefits.

These abstract concepts may be illustrated through a simple example. All societies are faced with the problem of coping with the capriciousness of the weather. A great deal of human suffering has been the result of the vagaries of rainfall, and history provides many examples of the tragic consequences of drought. A number of responses are possible when people are confronted with this problem. The simplest is to succumb to despair, and perhaps try to find meaning in it by attributing the drought to fate or God's will. A more active approach might be to offer prayers, perform a special ceremony, or sacrifice a member of the community. These latter activities are not likely to meet with success. There is no logical or empirically verifiable connection between them and the circumstances that produced the drought, a fact that could be demonstrated by a systematic inquiry into the long-term connection between prayers, ceremonies, or human sacrifices and the incidence of rainfall.

Attitudes and behaviors of this sort stand in sharp contrast with rational ones. Through the use of logic and empirical observation, it is possible to develop ways of dealing with problems like drought that are both more effective and more closely connected to the way the world actually works. A systematic and empirical observation of weather patterns might allow the prediction of a drought so that necessary steps can be taken to alter farming practices and conserve water. Other solutions could be the development of drought-resistant crops, improved methods of conserving water, and the distillation of sea water. It might also be possible to artificially stimulate rainfall through cloud seeding. In short, a rational approach to problem solving is continuously concerned with identifying and developing appropriate means for achieving particular ends.

These remarks are not meant to convey the ethnocentric belief that modern Western culture is superior to all others. The intention here is not to ridicule the beliefs and practices of people and societies that use nonrational approaches to problem solving. There is no reason to believe that rationality has been and always will be the special attribute of a particular group of people. Moreover, modern societies often manifest behaviors and patterns of thought that are anything but rational, as when large numbers of people continue to find value in astrology, numerology, and the predictions of supposed psychics.

It is also important to recognize that rational ways of thinking do not confer moral superiority. To the contrary, the rigorous development and use of rational procedures can be accompanied by major moral and ethical transgressions. The rational method of problem solving, with its overarching concern for devising appropriate means for attaining particular ends, makes no distinction concerning the ends being pursued. There is nothing in the rational approach to the world that prevents the use of logically and empirically derived means in the service of goals that are neither rational nor ethically justifiable. We can take note of the words of Captain Ahab, the main figure in Herman Melville's novel *Moby Dick*: "All my means are sane, my motive and subject mad." Nazi Germany provides many ghastly historical examples of human destruction ensuing from rational thinking and its resultant technologies. As Albert Speer, Hitler's Minister of Armaments, ruefully noted, "The criminal events of these years were not only an outgrowth of Hitler's personality. The extent of the crimes was also due to the fact that Hitler was the first to be able to employ the implements of technology to multiply crime."[16]

Even when rationality is not used for manifestly immoral purposes, it can still leave a dubious spiritual legacy. The very strength of rationality and the scientific and technological accomplishments that flow from it lie in their matter-of-fact approach to the world. A rational approach to things is often accompanied by a reluctance to admit there are any forces incapable of withstanding logical and empirical scrutiny. As the great German sociologist Max Weber put it, the world defined by rational thought processes had become "disenchanted," for it was bereft of the gods, genies, and spiritual forces that people not imbued with the spirit of rationality used to explain their world.[17] But "disenchantment" is a two-edged sword, as the everyday meaning of the word makes clear. To be disenchanted is to lose the sense of awe, commitment, and loyalty that is a necessary part of a meaningful existence. Weber's melancholy analysis of a world that has lost its enchantment is summarized by the French sociologist Julian Freund:[18]

> With the progress of science and technology, man has stopped believing in magic powers, in spirits and demons; he has lost his sense of prophecy and, above all, his sense of the sacred. Reality has become dreary, flat and utilitarian, leaving a great void in the souls of men which they seek to fill by furious activity and through various devices and substitutes.

Similar misgivings were voiced by the eighteenth-century political philosopher Edmund Burke. Burke's primary concern was the destruction of traditional authority by modern mass movements, as exemplified by the French Revolution. Burke attributed much of the demonic energy of that movement to the spread of rational modes of thought that left no room for the traditional attitudes, values, and political structures that had long sustained European civilization. Burke's comment on the downfall of the queen of France, Marie Antoinette, thus contains a sharp indictment of the bearers of rational values who, in his estimation, were leading Europe to its doom:[19]

> Little did I dream that I should have lived to see such disasters fallen upon her in a nation of gallant men, in a nation of men of honor and of cavaliers. I thought ten thousand swords must have leaped from their scabbards to avenge even a look that threatened her with insult. But the age of chivalry is gone. That of sophisters, economists, and calculators, has succeeded; and the glory of Europe is extinguished forever.

Rationality also implies objectivity; coolness and detachment are part of the rational approach to understanding and changing the world. Guided by a rational outlook, scientific inquiry and technological application are usually based on the abstraction or isolation of the part of the natural world that is being studied or manipulated. This isn't always a good thing, for it can produce a sharp separation between the individual and the rest of the world. The scientist or technologist stands apart from the system that is being studied and manipulated, resulting in a kind of tunnel vision that all too often ignores the larger consequences of gaining and applying knowledge.[20] For example, in discovering a genetic marker for a serious disease, a researcher might not consider potential abuses of that discovery, such as insurance companies refusing coverage of people with that marker.

It also may be argued that a logical, detached, and dispassionate approach to the world is suffused with a "masculine" approach to understanding and interacting with the world. Some technologies have largely been a male domain, but throughout history women also have made significant contributions to technological advance.[21] The complex relationship of gender and technology is illustrated by the history of the technological artifact most strongly associated with the present era, the digital computer. Its development has generally been viewed as the product of hyper-rational male engineers, mathematicians, scientists, and technicians. In reality, many of the programmers of first-generation computers were women whose accomplishments have often been passed over in standard histories.[22] More recently, the development of computer technology has depended on thought processes that are relentlessly rational, objective, and logical, but at the same time has required an intuitive, interactive, and generally less structured approach.[23] This is not to say that either style is the exclusive province of men or women, only that technological advance often requires both approaches. Equally important, although these modes of thinking may be described in gender terms, they need not reflect the cognitive approaches of individual men and women.

Technological Determinism

Nothing worthwhile in life comes without some costs attached. So it is with technology; while it has expanded human power and made our lives materially richer, the advance of technology has created many problems—environmental degradation, alienation, and the threat of nuclear annihilation, to name only the most obvious ones. And, most bothersome of all, there looms the possibility that technology is out of control. If this is so, what began more than a million years ago as a human creation has taken on a life of its own, with technology advancing according to its own inner dynamic, unrestrained by social arrangements, systems of governance, culture, and thought.[24] The belief that technology acts as an independent force in our life, unaffected by social forces, is known as "technological determinism," and if it is true, we have become the servant of technology instead of its master.

There can be little question that technology exerts a great influence on social, political, and economic relationships. Everything from antibiotics to zippers has affected our lives to some degree; many of these influences will be explored in subsequent portions of this book. But that is not the end of the story. As will be explored at greater length in Chapter 3, students of technology have given extensive consideration to the opposite possibility, that instead of operating as an independent force, technology is shaped by social arrangements. According to social constructivists (adherents of the Social Construction of Technology approach), the emergence of particular technologies, choices between competing technologies, and the way these technologies are actually used owe a great deal to socially grounded forces like political power, social class, gender, and organizational dynamics.

Asserting the supremacy of either technological determinism or social constructivism is not a very useful activity. Such straightforward cause-and-effect relationships can be found in some realms—Newtonian physics, for example—but technological and social change is better understood in terms of probabilities, reciprocal interactions, and feedback loops. Even William F. Ogburn, a sociologist who is often characterized as a technological determinist, on occasion took a more nuanced view of the subject: "The whole interconnected mass [i.e., social institutions, customs, technology, and science] is in motion. When each part is in motion and banging up against some other part, the question of origins seems artificial and unrealistic. If one pushes the question to the extreme, origins are lost in a maze of causative factors."[25]

The wondrously complicated interactions of technology and society often result in unimagined consequences when new technologies emerge. To take one example, when the first digital computers appeared in the mid-1940s, they elicited modest expectations about their future applications. Today, the world as we know it is almost unimaginable without computers, as everything from air travel to the mapping of genomes is totally dependent on the storage, retrieval, and manipulation of information performed by computers. Accordingly, the history of the computer would seem to lend credence to technological determinism. Nobody saw it coming in the 1940s, but within a few decades the computer had become a universal and essential part of contemporary life.

This is the story from a technological determinist standpoint, but social constructivists would challenge it by noting that the technical development of the computer in the 1950s and 1960s was heavily supported by military expenditures, just as one of today's major computer applications, the Internet, was initially a creation of the U.S. Department of Defense. Someone taking a social constructivist approach might also point out that the expansion of the market for computers was also powerfully stimulated by commercial enterprises like banks and insurance companies, and that this huge market supported the research and development that rapidly advanced computer technology.

A similar story could be repeated for most successful technologies. New technologies bring changes to many aspects of society, while at the same time social forces do much to stimulate and shape these technologies. To try to assign primacy to one or the other is to ignore a crucial feature of technological and social change. Both are dynamic processes characterized by the reciprocal interaction of a host of factors, some of them narrowly technical in nature, others not. No reasonable person could deny that technology has been a major force in making the world we live in, but it is important to always keep in mind that technology has not operated as an agent independent of the society in which it is imbedded.

Social constructivism therefore offers the possibility for more human agency than technological determinism, but it is not likely that the ability to influence the course of technological change will be evenly distributed among the population as a whole. To the contrary, social constructivist analyses have often shown how differences in power and access to resources have shaped technological change. Particular technologies may be devised, selected, and disseminated because they serve the interests of a particular group, possibly in opposition to the interests of other groups. Technology confers power, but this power is not wielded over only the nonhuman universe. As C. S. Lewis has reminded us, "Man's power over nature is really the power of some men over others with nature as their instrument."[26]

Living in a Technological Society

The development and application of technologies that are suited to our needs requires the informed participation of a wide range of people. Unfortunately, the very nature of modern technology places severe limits on popular understanding. The sophistication and complexity of contemporary technologies preclude direct involvement by all but those immediately concerned with them. The rest of us are passive consumers, content to reap the benefits of rationally derived knowledge but woefully ignorant of it. This creates the fundamental paradox of modern society: technology has generated massive powers available to human society, while as individuals we exert very little of that power. We have access to a wide range of powerful technologies, yet our inability to understand them often leaves us with feelings of impotence and frustration, as anyone who has experienced a computer crash will attest.[27]

As has been noted, the application of rationality for the solution of human problems is both the consequence and the cause of optimism and a willingness to accept constant change. Yet one cannot help but wonder if these characteristics can be sustained in an environment that sharply limits participation and inculcates widespread feelings of having little or no power over the process of technological change.

Strange notions can emerge when feelings of powerlessness are coupled with an extravagant faith in technology. The consequences of this combination are sometimes exhibited by fervent believers in alien spacecraft or UFOs (unidentified flying objects). Although convincing evidence of UFOs is lacking, a belief in their existence does not necessarily make one a crackpot. In some cases, however, a strident belief in the existence of UFOs takes on the characteristics of membership in a religious cult where the deities are superior beings who have produced an advanced technology. Alien space ships represent a level of technical sophistication not attained on Earth, and some UFO enthusiasts entertain the hope that the aliens that created them will take over this planet and solve its problems. Faith in a higher technology may be combined with a mistrust of the "establishment," as a fair number of UFO adherents claim that their government is engaged in a massive conspiracy to prevent the general public from being aware of the existence of UFOs. There is no denying that on occasion governments lie to their citizens, but a cover-up of the required magnitude would be impossible for even the most well-organized government to pull off. Still, conspiracy theories strike a resonant chord with people who feel that they have been excluded from decision making, both political and technological. A quasi-religious belief in UFOs may therefore combine an excessive confidence in technology in general with a distrust of the people and organizations that control it in actual practice.

Distrust flourishes when people have no ability to participate in decisions that shape their lives, and the inability to affect the course of technological change can produce a mixture of naïve hope and paranoid reaction. A realistic sense of control, including a sense of having some control over technology, is essential for an individual's mental health. No less important, widespread participation in the shaping of technology is essential for democracy. Technology's benefits cannot be separated from its costs, and thus it becomes necessary to determine if the former justify the latter. If a society is truly democratic, such decisions will be made with as much citizen participation as possible. Moreover, the benefits and costs of technology are not shared equally, and once again the apportioning of costs and benefits should be done in as participatory a manner as possible. We will return to these themes in Chapter 17, but first we will take a closer look at how technology can affect people and groups in different ways.

Questions for Discussion

1. In your opinion, which recent technology has produced the greatest benefit? Which has produced the most harm? Are there any harmful elements to the beneficial technology, and has anything good come from the harmful one?
2. Do all technologies require material artifacts of some sort? Does it make any sense to speak of *bureaucracy* as a kind of technology?
3. Are technologies "gendered"? Are some technologies identified with women and others with men? On what bases do we make these distinctions? Will this situation necessarily continue in the years to come?
4. Can you think of any technologies that were developed simply because of the technical challenges involved? How can these "impractical" technologies be justified?
5. How do you feel when a technological device upon which you depend malfunctions? What do these feelings tell you about your attitude toward technology in general?
6. It is sometimes asserted that the development and use of oral contraceptives were responsible for the sexual revolution that began in the 1960s. Is there a simple cause-and-effect relationship of the two? Have there been any other forces that contributed to changing sexual mores?

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chapter two

Winners and Losers: The Differential Effects of Technological Change

The last chapter may have seemed a bit negative in its assessment of technology and the culture that supports it. In one regard, however, there is no denying technology's positive consequences: technological advance has been the greatest single source of economic growth. If our material lives are better than those of our grandparents, it is largely because technological development has boosted the production of goods and services. Equally important, it has created entirely new products while at the same time improving the quality of existing ones.

Curiously, economists were slow to grasp this seemingly obvious fact. Conventional economic analysis identifies three basic "factors of production": land (which includes natural resources), labor, and capital. Any increase in production is therefore taken to be the result of an increase of these factors. This view began to change in the 1950s when the historical course of economic development in the United States was analyzed through the use of sophisticated statistical techniques. It then became apparent that increases in the traditional factors of production did not adequately explain the actual record of economic growth. The amount of land had remained constant, and capital accumulation and increases in the labor force accounted for only 10 to 20 percent of economic growth during the first half of the twentieth century.[1] Accordingly, the major source of economic growth was a "residual" factor of overwhelming importance. Most economists agree that technological advance is the main element of this residual, although organizational development and improved worker skills, along with economies of scale, are also key components. Still, as we have already seen, organization and skill are integral parts of technology, so it is reasonable to consider technological change as the major source of economic growth.

Technology as a Subversive Force

While technological development has been the primary source of economic advance, it has not been cost-free. One of the most pleasant myths about technology is that it can work its wonders without altering existing social arrangements. Americans in particular have often seen technological progress as the surest basis for progress in general, and have tended to believe that technological solutions to problems are less painful than solutions that require political or social changes.[2] These beliefs are not easily sustained after an examination of the actual pattern of technological advance.

It is a truism that a particular technology can be used for either good or evil purposes; a construction team employs explosives to build a road, while a terrorist uses them for roadside bombs. But there is less appreciation for a more subtle point: technological change is often a subversive process that results in the modification or destruction of established social roles, relationships, and values. Even a technology that is used exclusively for benign purposes will cause disruptions by altering existing social structures and relationships. There are many technological changes that are small in scope, the effects of which are felt by only a few. A few technological changes are massive, and they lead to vast social restructuring. In either case, technology does not yield its benefits without exacting a cost.

The disruptive effects of technological change can readily be seen in the economic realm, where new technologies can lead to the destruction of obsolete firms, as when the fabled Pony Express rapidly lost its customers after telegraph wires had been strung across the West. Of course, sometimes the disruption is less apparent when technological innovation results in the creation of entirely new industries that are not in direct competition with existing ones. Many new industries and individual firms owe their existence to the emergence of a new technology. Witness, for example, the rapid growth of personal computer manufacturing, peripheral equipment production, software publishing, and app development that followed the invention of the integrated circuit. Even so, lurking behind these successes were a number of failures, most notably the manufacturers of vacuum tubes and transistors, who faced a diminished market for their products.

Concerns about the disruptive effects of technological change are not new, as can be seen in an English magazine editor's fulminations against the first railroads in 1835: "Railroads, if they succeed, will give an unnatural impetus to society, destroy all the relations that exist between man and man, overthrow all mercantile regulations, and create, at the peril of life, all sorts of confusion and distress."[3]

Anyone convinced of the virtues of technological change could easily criticize this reactionary view by noting how the railroad stimulated economic development and produced many social benefits. Even so, there is more than a grain of truth in the concerns expressed by the agitated magazine editor. Technological changes, both major and minor, often lead to a restructuring of power relations, the redistribution of wealth and income, and an alteration of human relationships.

The experiences of the Yir Yoront, a group of Australian aboriginals, gives us an excellent, albeit sad, example of the disruptive effects of a new technology.[4] The Yir Yoront were a truly paleolithic people whose highest technological achievement was the stone axe. These axes were simple implements, but a considerable amount of skill went into their production. Several different materials had to be gathered—wood for the handle, bark for binding, and gum for fixing the head to the handle. The stone itself was obtained through an elaborate trading network that involved only adult males. The actual possession of the axes was also an exclusively male prerogative. Women and children could only borrow an axe, and even then only

Technological change may contribute to the decline of many established products and organizations. The closure of the Borders bookstore chain was due in part to the growing popularity online ordering and e-readers. (David L Ryan/The Boston Globe via Getty Images; RICHARD B. LEVINE/ Newscom) from close relatives. The axe also had an important symbolic value, for it was a totemic symbol that was used in certain religious ceremonies performed by men only. Thus, the production and use of the axes reflected and reinforced traditional social relationships based on age, sex, and kinship.

All this changed when steel axes began to be introduced into Yir Yoront society during the early twentieth century. These axes were dispensed as gifts by missionaries, and they were given to all "worthy" members of the society, including women, young men, and even children. As a result, mature men lost an important indicator of their distinctive status. At the same time, the trading networks between men of different tribes were bypassed. In their place new trading relationships emerged, with some men even prostituting their wives in return for the axes. The possession and distribution of axes no longer symbolized traditional relationships; a certain kind of freedom was achieved, but at the expense of confusion and insecurity. A more general malaise spread through the entire tribe, for the steel axes had no clear links with the religiously based explanations of how the world came to be as it was; they were alien objects whose origin could not be explained. Symbolically, steel axes represented a new world that the Yir Yoront could not comprehend. The result was rapid cultural disintegration and a bewildered and apathetic populace.

To be sure, it wasn't the axes themselves that produced these disruptions. Steel axes were part of an outside world that was impinging on the traditional aboriginal order. Stone axes were an integral part of the indigenous technological system, while steel axes were alien intrusions that represented both a new technology and a new pattern of social relationships. For the Yir Yoront, the two were so closely intertwined that the introduction of a new artifact produced a social and cultural crisis that could not be surmounted.

Preindustrial people are not the only ones subject to the unpleasant consequences of technological change. On occasion, technological advance has fatally disrupted modern communities and the people living in them. One such place was Caliente, Nevada.[5] Caliente was a small town with a variety of civic amenities—schools, churches, a hospital, a theater, a park, and many prosperous small retail businesses. Many of its inhabitants were proud members of civic organizations such as the Chamber of Commerce, the Rotary, the Masons, and the American Legion. It was a typical American small town, with typical American small-town values.

The life of the town was supported by a single industry: the servicing of steam locomotives. Caliente was an important division point on a transcontinental railroad, and many of the town's people worked as machinists, boilermakers, and repairmen. Their incomes in turn supported Caliente's commercial and civic establishments. Then, in the late 1940s, the diesel-electric locomotive rapidly replaced the steam locomotive. Diesels had many advantages; they were more fuel-efficient, hauled longer trains, and did less damage to the rails and roadbed. They also required less frequent servicing. When servicing was required, it took place in large centralized shops. As a result, service facilities were eliminated at many division points, and Caliente was one of them. The town lost its economic base, and within a few years it had become a shell of its former self. People moved out, homes were abandoned, and shops were boarded up. The local newspaper sadly noted, "Employees who have

By providing many jobs, the servicing of steam locomotives formed the economic base of towns like Caliente, Nevada. (Jack Delano/Farm Security Administration—Office of War information Photography Collection [Library of Congress])

given the best years of their lives to this railroad are cut off without anything to which they can turn, many of them with homes in which they have taken much pride; while others, similarly with nice homes, are told to move elsewhere."[6]

The tragedy of this small town has been repeated in many other communities affected by technological change. Many places of employment have closed down as new products and processes have replaced old ones, leaving communities and their inhabitants in desperate straits. The technological advances that produced these dislocations may have benefited society as a whole, but at great cost to the people who were immediately affected.

Technological changes do not always result in the destruction or modification of an existing social order; sometimes they may help to preserve it, as happened when pneumatic molding machines were adopted by the McCormick reaper manufacturing plant in the 1880s.[7] These machines were not installed, as conventional analysis would lead us to think, in order to reduce costs or to produce a better product; in fact, they were deficient on both counts. They were installed for the sole purpose of eliminating the skilled workers who formed the backbone of the National Union of Iron Molders, an organization that was challenging the entrenched authority of McCormick's management. The molding machines allowed the replacement of skilled workers by unskilled ones, and three years later, having served their purpose, they were discarded by McCormick's management.

Groups that are threatened by a technological innovation are not always as helpless as the iron molders apparently were. Many affected parties have been able to defend themselves against changes in the way of doing things. To take one example, prefabricated buildings were vigorously resisted by many local construction workers' unions because they threatened their members' jobs. One sad tale is narrated by Peter Blake:[8]

> Shortly after the end of World War II, an enterprising manufacturer decided to mass-produce a so-called service core: a complete "package" containing kitchen, bathroom, and utility room, with all fixtures, pipes, ducts, and wires in place, ready to be plonked down in any typical suburban house.
>
> The first twenty of these beautifully designed and beautifully made "packages" arrived on a site near Detroit; local union plumbers and electricians promptly refused to install them. Finally, after nine months of heated debate (during which the units, parked on a sidewalk, were exposed to weather and vandalism), the local unions agreed to handle the "packages"—by disassembling them on the sidewalk and then reassembling them, piece by piece, in each of the houses. The manufacturer, needless to say, thereupon went out of business.

Nineteenth-century China provides another example of the efforts of a group of people defending their interests in the face of a potentially disruptive technological change.[9] For centuries, the Chinese had produced silk thread by manually unwinding silkworm cocoons. The technology employed, although unsophisticated, was adequate to serve a substantial domestic and export market. Then, in 1859, a representative of the British Jardine Matheson Trading Company arrived in Shanghai with the intention of building a modern factory that would use steam-powered machinery to reel the silk. The machinery required skilled labor for its operation, and many problems were encountered in mustering an adequate labor force. This obstacle was eventually overcome, and the factory enjoyed an adequate measure of technical success. Unfortunately, it was not an economic success, for the high price of its basic raw material, silkworm cocoons, was not offset by increased productivity, and the enterprise suffered chronic losses until it closed down less than 10 years after its founding. The significant point here is that the factory could not obtain cocoons at reasonable prices due to the opposition of an entrenched silk-makers' guild. Accustomed to monopolizing silk manufacture, the guild prevented most individual cocoon producers from having any dealings with the foreign operation, while the few who did were able to charge high prices for their wares. As happened with the disgruntled construction workers, the Chinese guild members effectively undermined a technology that threatened their established ways of doing things.

The Luddites

There have been many other occasions when individuals and groups have recognized that certain technological changes were not working to their advantage. In some cases, their reactions have taken a violent turn. The most famous of these are the outbreaks of machine-smashing that occurred in early nineteenth-century England.[10] These attacks were the work of different groups who were collectively known as Luddites, a name that was derived from one Ned Ludlum, an apprentice stocking maker who, as legend had it, answered his master's reprimand by smashing his stocking frames with a hammer. There was really nothing new about these attacks; the breaking of machines by disgruntled workers had a long history in England, the earliest recorded episode taking place in 1663. But the Luddite disturbances that began in 1811 did represent a substantial increase in the scale of these attacks; by the following year, the government had to deploy 12,000 troops to restore order to the parts of England affected by the movement.

Since these attacks coincided with an era of rapid technological change, it is easy to draw the conclusion that they were motivated by the fear of many workers that their jobs would be lost to new machinery. The actual story is a bit more complicated. Luddite attacks occurred in a number of separate branches of the textile industry, and each was characterized by a distinctive set of motivations and responses. The Luddite movement began in the hosiery trades, where there long had been opposition to the use of wider stocking frames that allowed the employment of poorly paid unskilled labor for the manufacture of an inferior product. The situation might have been resolved in a peaceful manner had it not been for the dire conditions encountered by many of England's working people at the time. The Napoleonic wars had resulted in the closure of many export markets, leading to a general trade depression. To make matters worse, a series of bad harvests led to sharp increases in the cost of food, and many workers found that their wages were insufficient to meet their basic needs. These conditions produced a fertile ground for the spread of "collective bargaining by riot," and Luddite attacks were soon fomented by shearers in the textile industry. Another occupational group, the handloom weavers, viewed the advance of steam-powered weaving machinery with understandable apprehension, and, following the example of workers in the hosiery trade, some of them attacked the factories housing mechanized looms, as well as the houses of their owners. Only in a few instances was the machinery itself directly attacked.

Luddite disturbances were expressly oriented toward the prevention of technological change in the cropping trade. Wool cloth was traditionally finished by raising the nap and then leveling the surface through the use of a heavy set of shears. The growing use of the gig mill, a device for raising the nap, along with the employment of a crude device for the mechanized cropping of cloth, threatened the livelihood of the traditional hand workers. They responded with some of the most severe attacks of the Luddite epoch. Although the machinery had been used for many years in many textile establishments, the severe economic conditions of the time brought matters to a head. More than the other instances of Luddite revolt, the attacks on cropping equipment were motivated by a deep fear of unemployment induced by technological change.

Within a few years the Luddite assaults came to an end due to the deployment of government troops; the execution, imprisonment, and exile to Australia of a number of the participants; and the general improvement in living conditions after the defeat of Napoleon. The succeeding decades of the nineteenth century also saw the replacement of the small manufacturing establishment by the large factory. Machine-smashing by riotous crowds was a likely form of labor protest when workers were scattered and lacking in permanent organizational linkages. In contrast, the large factory served as a fertile ground for the development of labor unions and other organizational vehicles for pressing the interests of workers. Industrial sabotage did not come to an end, but it was generally superseded by unionization and more effective forms of worker protest.

Neo-Luddism

These early episodes of machine-smashing have led to the application of the "Luddite" label to anyone opposed to modern technology. But it is perhaps unfair to impute to the original Luddites a hostility to technology per se. As we have seen, most instances of Luddism were not motivated by a fear and hatred of new machinery; their grievances were those of people suffering from the low wages and unemployment caused by a generally depressed economy. The machines were seen as convenient targets of their ire rather than the sources of it.

This is not to say that attacks on new technologies are always motivated by concerns that transcend the technology in question. As the pace of technological change has quickened and people have become more aware of its consequences, numerous efforts have been made to prevent or restrict the spread of technologies that are perceived as threats. For example, computerization in its initial stage posed a threat to many established occupational roles and procedures, resulting in a fair amount of resistance to computer installation and use. In one case that received a good deal of national publicity during the mid-1970s, newspaper linotype operators in Washington, D.C., demonstrated their opposition to computerized typesetting equipment by engaging in large-scale industrial sabotage.

Another striking expression of Luddite sentiments appeared in 1995 when *The New York Times* and the *Washington Post* published a lengthy critique of modern society and the pivotal role of technology in creating and maintaining it. According to its author, a society based on modern technology brings some material comforts, but "all these technical advances taken together have created a world in which the average man's fate is no longer in his own hands or in the hands of his neighbors and friends, but in those of politicians, corporation executives and remote, anonymous technicians and bureaucrats whom he as an individual has no power to influence."[11] Regaining human freedom therefore required the total destruction of industrial society and the technologies that made it possible. This would not be a peaceful revolution, but one that required the destruction of factories, the burning of technical books, and the eradication of all of the components of an industrial civilization. This creed might have been dismissed as the agitated musings of a late twentieth-century Luddite, but its author was not just a misguided critic of the modern world. Shortly after the publication of the manifesto, it was discovered that its author was Theodore Kaczynski, dubbed by the media as "The Unabomber," an elusive figure who from 1978 to 1995 had been responsible for 16 bombings that killed three people and wounded 23 others.

Whose Technology?

We have just seen how specific technologies have been used and resisted by particular groups in accordance with their own needs and concerns. These examples should help us to realize that technology does not proceed solely through its own momentum, as implied by technological determinism; its development is strongly influenced by existing social and political arrangements. Technological changes may take place because they advance the interests of a particular group. Conversely, some technologies may meet with stiff resistance because they threaten a group's interests. Technologies do not stand or fall solely on their intrinsic merits. The decision to develop and deploy a new technology is often shaped by the distribution of power in a society.

Social and political arrangements affect the course of technological change by influencing the kinds of investments that are made, the research projects that are funded, and the general priorities that are established.[12] Large organizations, such as corporations and government agencies, often wield disproportionate influence over the process of technological change. As we will see in Chapter 17, the federal government is a major source of financial support for research and development, with the Department of Defense, the National Aeronautics and Space Administration (NASA), and the Department of Energy (primarily for nuclear research and development) accounting for a large share of these expenditures. Although we can only speculate about alternative outcomes, it seems likely that American technology would have diverged markedly from its historic path if financial resources had been distributed differently.

Perhaps with a different set of sponsors, technological development might have made greater contributions to the solution of a number of pressing social problems, such as poverty and crime. At the same time, however, it can be argued that certain kinds of problems are simply not amenable to technological solutions. Even with significant changes in the funding of research, technological solutions to many social problems will not be forthcoming. This is an important objection, and we will examine it in the next section.

What Technology Can Do—And What It Cannot Do

The growth of technology has brought dazzling changes to our lives. At the same time, we seem to be mired in problems for which there seems to be no solution. The continued existence of these problems is all the more frustrating when contrasted with the rapid progress of technology. For example, we can use all kinds of sophisticated medical equipment and techniques to preserve the lives of sickly infants who have been born many weeks premature, but we can't seem to conquer the poverty that often results in sick infants. Why, it is often asked, is there such a gulf between technological progress and social progress? Why can't technology be applied as a solution for more, if not all, of our problems? If we can put a man on the moon, why can't we. . . ?

The Technological Fix

These are troubling paradoxes, and in recent years we have searched for ways of finding technological solutions to a host of problems. The drug methadone has been widely used to eliminate addicts' cravings for heroin. As highway accidents continue to result in tens of thousands of deaths and hundreds of thousands of injuries each year, efforts have been mounted to develop and manufacture cars capable of protecting their occupants from the consequences of incompetent driving. Cities befouled by graffiti have turned to the use of new paints and cleaning solutions that resist the endeavors of spray-can artists. Overweight men and women spend billions of dollars annually on medications, diet books, and exercise apparatus in the hope of shedding excess pounds.

The list of technologies that have been or could be applied to the alleviation of social problems is an extensive one, and examples could be supplied almost indefinitely. What they have in common is that they are "technological fixes," for they seek to use the power of technology in order to solve problems that are nontechnical in nature. In this section we will briefly examine a few of these technologies and consider the extent to which technology can alleviate these pressing problems.

One study of a number of technologies directed at the solution of social problems bears the significant title "Technological 'Shortcuts' to Social Change."[13] The authors examined a number of case studies, ranging from instructional television to intrauterine devices for birth control. As might be expected, the application of different technologies for the solution of social problems resulted in varying degrees of success, but a few generalizations can be made about the efficacy of technological solutions to social problems.

First, even if a technology "works" by producing the desired result, the actual mechanisms through which the technology produces a change are often poorly understood. This is particularly evident when the technology is used in conjunction with other interventions, such as the coupling of methadone maintenance with individual counseling. Technological shortcuts also produce uneven results; they work when applied to some segments of the targeted population but do nothing for the rest. Above all, technological solutions only eliminate the surface manifestations of the problem and do not get at its roots. A methadone program does not address the social and psychological causes of drug addiction, and improved methods of removing graffiti do nothing to mitigate the anger and alienation that may motivate the defacement of public spaces. These criticisms aside, technological shortcuts may be effective in alleviating a range of problems, and even though these problems may not be eliminated, their alleviation may at least come at a lower price than would be the case if nontechnological efforts at solutions were employed.

Many other technological fixes have been employed over time, although not always with the conscious understanding that technology was being used in lieu of some other method of achieving a desired end. To take one example, at the beginning of the twentieth century the United States was undergoing severe growing pains; the urban population was expanding at a rapid rate, accompanied by congestion, pollution, and a host of other urban ills. In a nation steeped in the

Jeffersonian belief that cities were inherently evil and that the countryside was the best location for virtuous living, the conversion of the American populace into a race of unhealthy and disaffected city dwellers was viewed with alarm. A number of technologies did make urban life more tolerable, most notably those concerned with public health and sanitation, but these only served to ameliorate living conditions without addressing the real issue: the desire of many Americans to escape the city and return to a vaguely perceived rural idyll.

The pursuit of this goal gave a great impetus to the development of transportation technologies that would allow the solution of urban problems by eliminating the need for cities, at least as places of residence. Instead of comprehensively addressing urban ills through planning and the development of social programs, Americans pinned their hopes on new transportation technologies. The first of these was the electric trolley. Through the construction of extensive networks of interurban electric lines, it was hoped, America's urban problems could be literally left behind as a new generation of workers could commute from their places of work to their rural or suburban homes.[14]

In many American cities the trolley was displaced by the automobile, yet a great deal of automobile ownership was motivated by similar sentiments. Widespread automobile ownership promised an escape from the harsh realities of America's cities through individual commuting. As Henry Ford neatly summed things up, "We shall solve the city problem by leaving the city."[15] Ford's sentiments were taken to rhapsodical levels by one early twentieth-century journalist:[16]

> Imagine a healthier race of workingmen, toiling in cheerful and sanitary factories, with mechanical skill and tradecraft developed to the highest, as the machinery grows more delicate and perfect, who, in late afternoon, glide away in their own comfortable vehicles to their little farms or houses in the country or by the sea twenty or thirty miles distant! They will be healthier, happier, more intelligent and self-respecting citizens because of the chance to live among the meadows and flowers of the country instead of in crowded city streets.

It is hardly necessary to note that these hopes were not realized. The mushrooming growth of suburbs spawned by trolleys and automobiles did not create a harmonious social order based on rural values. All too often the legacy has been suburban sprawl, the deterioration of city centers, visual blight, pollution, traffic fatalities, and many other social costs. This is not to say that the automobile has been an unmixed curse; the benefits of personal mobility, privacy, and a sense of power have been too eagerly accepted to allow such a judgment. But the automobile, just like its predecessor the trolley, was hardly the technological panacea that was envisioned. The examples of the trolley and the automobile remind us that while some specific problems may be amenable to technological solutions, larger issues rarely admit of easy solutions through the application of technological fixes.

Why Technology Can't Always Fix It

The main difficulty underlying the use of technology to solve social problems is that these problems are fundamentally different from technical problems. In the first

The trolley held out the promise of an escape from the noise, dirt, and congestion of the early twentieth-century city. (The Chicago Historical Society)

place, social and technical problems differ in their specificity. If you intend to design an air conditioner, you at least know what your goal is: to keep a space cool. In many ways this problem is similar to the far more grandiose objective of landing a man on the moon; although there may be daunting technical problems to overcome, at least the goal is clear and unambiguous. But what if your goal is to reduce crime? Crime, unlike air temperature, is a very diffuse concept, encompassing everything from forgery to murder. Even when a particular crime is singled out for treatment, its causes are likely to be manifold and not easily addressed by a single technology.

To make matters even more difficult, social problems are directly concerned with human motivations and behaviors. It is one thing to change the temperature of the air by inventing and installing an air conditioning system; it is quite another to attempt to change human behavior through the same kind of technological intervention. Human beings are wondrously intricate creatures whose actions are governed by extremely complex motivations. Trying to understand, let alone change, human actions is an exceedingly difficult task. And humans are likely to resist when attempts are made to change their behavior.

It is also apparent that technological solutions work best when they operate within closed systems—that is, when the issue to be addressed is sealed off from outside influences. Of course, no technology exists in isolation from the surrounding society. A transportation system based on private automobiles, for example, is the result of choices exercised within the economic and political realm, such as a government's decision to build a highway network. But within a given technology there are many specific matters that can be treated as purely technical problems. In these cases, it is possible to approach the problem directly and not worry about the influence of other factors. If your car fails to start one morning, you can be sure that the problem lies only with its components; you need not concern yourself with sunspot activity or a recent presidential election in Peru. When a problem is not so easily isolated, a technological solution is much less likely. Today, millions of children are diagnosed with attention deficit hyperactive disorder (ADHD). This behavioral problem undoubtedly has a neurological basis, at least for some children, and amphetamines such as Ritalin are routinely prescribed to alleviate the symptoms of ADHD. It is likely, however, that many children afflicted with the disorder have problems that go beyond the neurological. Dysfunctional relationships and actions within a family can create stresses that produce ADHD. Under these circumstances, the administration of a drug will be insufficient. As the ADHD website of the National Institute of Mental Health notes, "Sometimes, the whole family may need therapy."[17]

As a final point, it should be noted that no problem, technical or otherwise, is ever really "solved." Not only are most solutions incomplete, they also generate new (and sometimes very different) problems. These "residue problems" may be considerably more intractable than the original problem.[18] This process has been dramatically illustrated by the rapid development of modern medical technologies, a topic that will be explored in greater depth in Chapter 7. Technical solutions such as the development of life-saving drugs, organ transplants, and sophisticated diagnostic techniques have proliferated, but at the same time they have created a host of new dilemmas. Given the expense of many of these new technologies, it may be necessary either to spend more on medical care or to attempt to ration it. If these technologies are to be rationed, will this take place through the price mechanism, or will it be done according to some formalized procedure? In either case, serious ethical issues will have to be faced. Life-extending technologies have also raised vexing questions about the morality of prolonging a life under conditions that seem dismal indeed. Moreover, a longer individual life span leads to an aging population and the necessity for a wide range of adjustments to the society, the economy, and even the culture. Without belaboring the point, it should be apparent that no set of technologies will make our lives better without requiring the enactment of other changes.

The Appeal of Technocracy

These inherent limitations have not deterred a number of individuals and groups from trying to convert social problems into technical problems. There have been numerous flirtations with technocracy—the governance of society by engineers and other people with technical expertise, who attempt to develop policies based on technical and "scientific" principles. There is no denying that the technocratic vision is at first glance an appealing one. In a world too often governed by venal and incompetent politicians, there is something very attractive about a system of governance that supposedly bases itself on logic and the use of expertise. Moreover, where conventional political systems of all types seem endlessly involved with apportioning pieces of a small pie, adherents of some form of technocracy often promise a social and economic order that produces an ever-expanding pie through the application of the methods that have served technological development so well.

The promises and pitfalls of a technocratic approach to the solution of social problems are well illustrated by the theories of Scientific Management, as developed by Frederick W. Taylor (1856–1915) and his followers during the early decades of the twentieth century.[19] Scientific Management arose in an era marked by a profound paradox: industrial production was increasing at a rapid pace, but at the same time American society was racked by large-scale and potentially explosive conflicts between workers and management. Many cures for labor unrest had been proposed, but for Taylor all of them missed the mark. Taylor had earned an international reputation as a metallurgical engineer, and his systematic studies on the cutting tools used for machining metal had resulted in major technological advances. If obdurate metals could be better controlled and shaped through the application of new technologies guided by scientific principles, why couldn't the same thing be done with workers?

To achieve this goal, Taylor and his colleagues developed a "scientific" regimen for studying work. The main technique used for this task was the time-and-motion study through which workers were systematically observed and their work motions precisely timed. Through an analysis of these observations and measurements Taylor came up with a supposedly optimum set of motions for a given job, all of them subject to rigid time constraints. Equally important, the development and administration of these motions were the business of management exclusively, and any attempt by workers to go about their tasks independently would necessarily result in wasted motions and general inefficiency. A basic tenet of Scientific Management was that the planning and organization of work had to be separated from its actual execution. Only specially trained managers had the time and expertise necessary for the devising of optimal methods of production. The prime obligation of the workers was to do what they were told to do.[20]

Although they had no power to plan and manage their own work, workers were supposed to benefit from the system. Because their work activities were now optimized, production would supposedly increase significantly. Workers would necessarily share in these higher returns, for Taylor also advocated that workers be paid according to piece rates rather than straight wages; the more they produced, the more they earned.

The technocratic spirit of Scientific Management is thus evident: the tasks and prerogatives of management rested not upon the exercise of raw power but on management's technical superiority in guiding the production process. At the same time, Scientific Management promised relief from continual squabbling over relative shares of the fruits of production; an optimal system of organization would result in more of everything for everybody. Taylor was not content with using Scientific Management as a solution for the problems of the workplace; its principles, he claimed, "can be applied with equal force to all social activities: to

THE MIDVALE STEEL CO.

Form D — 124. Machine Shop......................18.........

ESTIMATES FOR WORK ON LATHES

OPERATIONS CONNECTED WITH PREPARING TO MACHINE WORK ON LATHES AND WITH REMOVING WORK TO FLOOR AFTER IT HAS BEEN MACHINED

OPERATIONS	TIME IN MINUTES
Putting chain on, Work on Floor	
Putting chain on, Work on Centers	
Taking off chain, Work on Floor	
Taking off chain, Work on Centers	
Putting on Carrier	
Taking off "	
Lifting Work to Shears	
Getting Work on Centers	
Lifting Work from Centers to Floor	
Turning Work, end for end	
Adjusting Soda Water	
Stamping	
Center-punching	
Trying Trueness with Chalk	
" with Calipers	
" with Gauge	
Putting in Mandrel	
Taking out "	
Putting in Plug Centers	
Taking out " "	
Putting in False Centers	
Taking out " "	
Putting on Spiders	
Taking off "	
Putting on Follow Rest	
Taking off " "	
Putting on Face Plate	
Taking off " "	
Putting on Chuck	
Taking off "	
Laying out	
Changing Tools	
Putting in Packing	
Cut to Cut	
Learning what is to be done	
Considering how to Clamp	
Oiling up	
Cleaning Machine	
Changing Time Notes	
Changing Tools at Tool Room	
Shifting Work	
Putting on Former	
Taking off "	
Adjusting Feed	
" Speed	
" Poppet Head	
" Screw Cutting Gear	
SIGNED TOTAL	

NAME ....
Sketch .... Number............
Order.............. Weight............
Metal.............. Heat No. ....
Tensile Strength.... Chem. Comp.......
Per cent. of Stretch ....
HARDNESS. Class..................

OPERATIONS CONNECTED WITH MACHINING WORK ON LATHES

OPERATIONS	Speed	Feed	Cut	Tool	Inches	Minutes
Turning Feed In						
" " "						
" Hand Feed						
" " "						
Boring Feed In						
" " "						
" Hand Feed						
" " "						
Starting Cut						
" "						
Finishing Cut						
" "						
Fillet						
"						
"						
Collar						
"						
Facing						
"						
Slicing						
"						
"						
Nicking						
"						
Centering						
"						
Filing						
"						
Using Emery Cloth						
" " "						
TOTAL						

Machining—Two Heads Used
" —One Head Used
Hand Work
Additional Allowance

TOTAL TIME
HIGH RATE
LOW RATE

Remarks

Time actually taken

INSTRUCTION CARD FOR LATHE WORK

Frederick Taylor, discussed on the previous page, believed that all kinds of work could be reduced to rationally derived actions, much as machining operations could be precisely timed through the use of this worksheet. (© 1911 by Frederick Winslow Taylor in Shop Management)

the management of our homes; the management of our farms; the management of the business of our tradesmen large and small; of our churches, our philanthropic organizations, our universities; and our governmental departments."[21]

The appeal of Scientific Management was not confined to the United States, or even to the capitalist world. No less a figure than Vladimir Lenin, the leader of the Bolshevik Revolution in Russia, expressed a deep admiration for American technology and American forms of industrial organization, and for Taylor's ideas in particular. Although he duly noted that Scientific Management embodied "the refined cruelty of bourgeois exploitation," Lenin made it clear that its basic principles and procedures could contribute to the realization of Soviet economic goals: "The possibility of building Socialism will be determined precisely by our success in combining Soviet government and the Soviet organization of administration with the modern achievements of capitalism. We must organize in Russia the study and teaching of the Taylor System and systematically try it out and adopt it to our purposes."[22]

The Technocrat's Delusion

Although some of its elements, such as the use of time-and-motion studies, can still be found in contemporary managerial practices, Scientific Management in its pure form never took hold in the United States, the Soviet Union, or anywhere else. A number of technical problems impeded its use. Considerable skill was required for the administration of time-and-motion studies, and they were especially difficult to conduct in work settings not characterized by repetitious actions. But of equal or greater importance, both management and labor realized that the implementation of Taylor's system posed fundamental threats to their own interests. Most managers were highly reluctant to delegate their authority to the dictates of "scientific" procedures.[23] Workers, on the other hand, resented the loss of what little autonomy they had, and they widely believed—with considerable justification—that higher levels of productivity would result in the downward adjustment of piece rates, leaving them no better off than before the program had been enacted.

Scientific Management, like all technocratically inspired systems, ignored the distinction between technical and sociopolitical problems. Even if Scientific Management had generated the productive increases it promised—which is unlikely—it would still have been strongly resisted by those who had to submit to it. Scientific Management promised a conflict-free method of administration where no such thing was possible. Workers and managers had their separate interests, and each group was unwilling to entrust its fate to Taylor and his disciples.

The basic fallacy of Scientific Management, one shared by all other variants of technocracy, is that administration can replace politics. Administration is based on the application of rules that allow the realization of given ends. It is thus a manifestation of the rational spirit of applying the best means for the achievement of a particular goal. It does not, however, determine these ends. The Internal Revenue Service officials who administer the tax system are not the authors of the tax code. Around April 15 we may get angry about the perceived unfairness of the tax code, but it is pointless to blame the officials at the local IRS office.

Tax codes and other policies are formulated through choices made in the political arena. Neither technology nor administration can supply the values that form the basis of these choices. They cannot tell us what we should do with our lives, nor can they help us to resolve the fundamental issue that all societies confront: how to distribute fairly life's necessities and luxuries. The resolution of these issues will always be marked by sizeable differences of opinion and a good deal of conflict. The technocrat's hope that society can be run on the basis of engineering principles will always remain an illusion.

To summarize, technological changes inevitably produce social changes. These changes, in turn, do not affect everyone equally. Although many technologies produce widespread benefits, not everyone benefits to the same degree, and there are instances where particular individuals and groups lose out completely. A choice of technology is often a determination of who wins and who loses; it is therefore proper that affected parties have the opportunity to participate in the process. This issue will be taken up in greater depth in the last three chapters. At this point it can at least be hoped that without deflating the very real achievements of technology, some sense of its inherent limitations has been conveyed. Technology and the procedures underlying its development have been immensely powerful in their own realm; outside this realm, however, they are less likely to be effective. Equally important, the methods that have been so successful in developing and applying new technologies cannot be transferred to the governance of society. Technological development may make some aspects of our lives better, but it can never substitute for a just and effective political and social system.

Questions for Discussion

1. Technological advance has often undermined established businesses. Most recently, the growth of Internet-based e-commerce has posed a threat to conventional bricks-and-mortar retail firms. Can you think of other business enterprises that the Internet may damage or even destroy? Should anything be done to prevent this from happening?
2. The story of the distribution of steel axes to the Yir Yoront seems to be a prime example of technological determinism. Is it possible that the story is not as straightforward as presented in this chapter? Might there have been any non-technological changes that contributed to the deterioration of Yir Yoront society?
3. Were the Luddites justified in mounting their attacks on machinery? How else might they have expressed their grievances? Would other kinds of actions have been more successful?
4. What examples of technological "fixes" can you think of? Have they been successful or not? What are your criteria for judging success and failure?
5. Political leaders at home and abroad are occasionally described as "technocrats." What are the implications of this description? Would you be more or less likely to vote for somebody who was described in this way?

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2

part two

The Process of Technological Change

Much of the research, writing, and thinking about the relationship of technology and society centers on how particular technologies have affected some aspect of the latter. But how do new technologies come into being in the first place? Chapter 3 describes how social processes are at the core of technological innovation and examines two modes of technological change in that light—epochal transformations and less dramatic incremental ones. It describes how economics, politics, culture, and social arrangements have influenced the trajectory of technological change. A market-based economy is an important stimulus for technological innovation, but nonmarket forces—ranging from human curiosity to government institutions—are also stressed.

Scientific discoveries are often seen as the major source of technological advance, but Chapter 4 argues that this is at best a half-truth. Although science and technology have much in common, they do not interact in a straightforward manner. When they do interact, the commonly accepted relationship between scientific and technological advance may be inverted as technological advances propel advances in science.

Chapter 5 shifts the focus from the creation of technologies to the ways in which they spread, or diffuse. It pays particular attention to the pitfalls of transferring a technology from one social and cultural environment to another and from one business firm to another. The patent system can be both a stimulus and an impediment to the diffusion of new technologies; its role in technological advance is examined in the final section.

chapter three

The Sources of Technological Change

What accounts for the emergence of particular technologies? Why do they appear when they do? What sort of forces generate them? How is the choice of technology exercised? To put it more concretely, why were digital computers developed only during the second half of the twentieth century even though their basic principles were understood more than a hundred years earlier? Why did photography undergo rapid development during the nineteenth century? What were the inventors of radio trying to accomplish, and how did their intentions differ from those of subsequent developers? These are some of the questions that this chapter will address as it considers some of the most basic issues in the study of technology.

Technological Change as a Social Process

As a starting point, it is important to keep in mind that technological change does not take place in a social vacuum. Technology is a human creation, and because humans are social creatures, technological change is necessarily a social process. In recent years, the study of technological change has been strongly influenced by a perspective known as "social constructivism," which we looked at in Chapter 1. According to this approach, technological change does not occur because new devices and processes demonstrate their clear-cut superiority over other ways of doing things. For social constructivists, the analysis has to begin with the need to explain why certain technologies are assumed to work better than others.[1] As Wiebe E. Bijker has noted, social constructivism is predicated on a belief in "the malleability of technology, the possibility for choice, the basic insight that things could have been otherwise."[2] To explain why things turned out the way they did, social constructivists describe how social structures and processes have affected choices of technologies. Since the presence of interest groups and unequal distributions of power are fundamental aspects of every society, social constructivists are particularly interested in delineating the main actors involved in the development and selection of particular technologies, and in noting how their actions reflect their positions in society. Accordingly, for scholarly practitioners of social constructivism, technological change is an inherently political process. New technologies do not succeed or fail solely on the basis of narrow technical merits. Rather, the achievement of technological "closure" (the point at which a particular technology is recognized as the accepted way of doing things, while others disappear or are marginalized) is closely tied to the presence of specific interest groups and their ability to affect the selection process.

Some form of social constructivism informs most contemporary studies of technological change, but considerable variation can be found in the relative emphasis put on social versus technical factors. Moreover, some students of technological change, most notably Thomas P. Hughes, have argued that the strength of the social constructivist approach may depend on the developmental stage of a particular technology. According to Hughes, social constructivism is most valid when a technology is at an early stage of development. Social, political, and economic forces are likely to exert the greatest influence when several alternative technologies emerge at about the same time.[3] Conversely, once a technology has become well established, it becomes difficult to deviate from the path that has been laid out by technical requirements. For example, at the end of the nineteenth and beginning of the twentieth centuries, motorists could choose between cars with electric, steam, or internal combustion power plants. The triumph of the latter was not simply a matter of technical superiority, but was a reflection of the needs and expectations of the individuals who were the prime purchasers of automobiles.[4] Once automobiles powered by internal combustion engines became well entrenched, the adoption of another type of automobile engine became extraordinarily difficult because the basic elements of our personal transportation infrastructure were firmly in place, everything from the fuel used to the skills necessary for effective repair work. Under these circumstances, technical requirements will prevail.

The Great Breakthrough

One benefit of the social constructivist approach is that it challenges the belief that technological change largely stems from the insights and labors of a few supremely talented individuals. Popular histories of technology have often looked to individual genius as the chief source of technological advance; we have all heard or read stories of how the inspired labors of Thomas Edison or the Wright brothers produced epochal inventions that transformed the world. Histories written from this point of view are in essence biographies of great inventors whose brilliance is assumed to be the sole source of technological advance. Other histories of technological advance have remained within this framework but have looked to a different kind of genius as the source of advance. The key players here are not the inventors of new technologies but rather the entrepreneurs who make inventions into commercial successes by taking risks, moving into uncharted territory, and in general doing what hadn't been done before.[5] There have been some individuals who have been both inventor and successful entrepreneur—for example, Edwin Land, the inventor and moving force behind the Polaroid camera—but they have been rare. Entrepreneurs generally take other people's inventions and make them into commercial successes. From this perspective, the key figure in the development of the steel industry is not Henry Bessemer, the co-inventor of the iron-refining furnace that bears his name, but Andrew Carnegie, who laid the commercial and organizational foundations of the industry.

Arriving at a definitive determination of the relative importance of "great men and women" versus "social processes" in shaping the history of technology would require much more space than is available here. It can be noted, however, that an assessment of the relative contributions of the two has to take into account the fact that a great deal of technological change is the result of small, incremental changes. In contrast to the "heroic" approach to the history of technology, these involve the work of largely anonymous inventors, engineers, mechanics, and technicians. Although their individual contributions may seem modest, in aggregate they have been an extremely important source of technological advance.

These incremental changes often are the result of a learning process that occurs as a technology is used. Problems are identified and overcome, bugs are worked out, and improvements are made. In many cases, the cumulative results of these efforts are technological advances at least as important as those that stem from fundamental breakthroughs. In industries as different as petroleum refining and building construction, the major source of productivity improvements has been a multitude of small technological improvements that have resulted in large cumulative gains.[6]

This process is nicely illustrated by Louis Hunter's narrative of how the impressive development of nineteenth-century steamboats was the result[7]

> of plodding progress in which invention in the formal sense counted far less than a multitude of minor improvements, adjustments and adaptations. The story of the evolution of steamboat machinery in the end resolves itself in a large part into such seemingly small matters as, for instance, machining a shaft to hundredths instead of sixteenths of an inch, or devising a cylinder packing which would increase the effective pressure a few pounds, or altering the design of a boiler so that cleaning could be accomplished in three hours instead of six and would be necessary only every other instead of every trip. Matters such as these do not get into the historical record, yet they are the stuff of which mechanical progress is made.

One can also witness the far-reaching consequences of numerous small improvements in the development of railroad technology. According to one calculation, if the traffic loads borne in 1910 had been carried by railroads employing the technologies of 1870, the additional costs would have amounted to $1.3 billion by the latter date. Fortunately, by 1910 American railroads had benefited from improvements in the size of cars and the power of locomotives, which in turn were the result of steady evolution.[8] And so it goes today. Even though the railroad may be described as a "mature" industry, this pattern of incremental yet substantial technological development continues. American railroads have significantly lowered their costs through the implementation of a series of small improvements: better insulation for electrical components (thereby allowing higher power loads), improved turbochargers and fuel injection systems, higher compression ratios, more efficient motors in cooling radiators, two-speed cooling fans, redesigned air ducts, lower idling speeds, and the substitution of alternators for direct-current generators. By themselves, none of these innovations is terribly significant. But when they are all put together in a modern locomotive, the result is a 10 percent savings in fuel costs, and a gain of 24 percent in the ton-miles of freight carried per gallon of fuel consumed. When it is noted that railroads spend several billion dollars each year for fuel, the consequences of these improvements are all the more impressive.[9]

In a world where the ability to produce successful technological innovations is increasingly a requirement for a firm's success, if not its survival, each firm needs to tap every source of technological advance, no matter how modest it may seem. This is a point stressed by Anthony Athos and Richard Pascale in their book about American and Japanese management: "Careful scrutiny reveals that despite the exalted status of 'strategy' in the lexicon of American management, few great successes stem from one bold-stroke strategic thrust. More often, they result from one half-good idea that is improved upon incrementally. These improvements are invariably the result of a lot of 'little people' paying attention to the product, the customer, and the marketplace."[10]

The "D" in R&D

The process of making a technology work is often summarized by the abbreviation R&D, which stands for research and development. "Research" calls to mind images of cutting-edge work in well-equipped laboratories, where great breakthroughs produce dramatically new technologies. Research can be an exciting, even glamorous activity, and we naturally look to it as the basis of technological progress. It is the source of fundamental change in technology, like the invention of integrated circuits, cloning, and composite materials. Still, this sort of research rarely results in useable products. The realization of the potentialities created by research breakthroughs usually requires a lengthy process of development. Numerous problems have to be resolved, and, equally important, the new material or device has to be put into a form that allows it to be produced at a reasonable cost.

Here again we can see the importance of the slow, unspectacular improvements that turn a good idea into a working product or process. And here, too, we can often see a substantial outpouring of money. If basic research is an expensive process, development is often even more so. The development work that goes into preparing a new technology for actual production can entail massive expenditures for equipment, material, manpower, pilot plants, and the like.

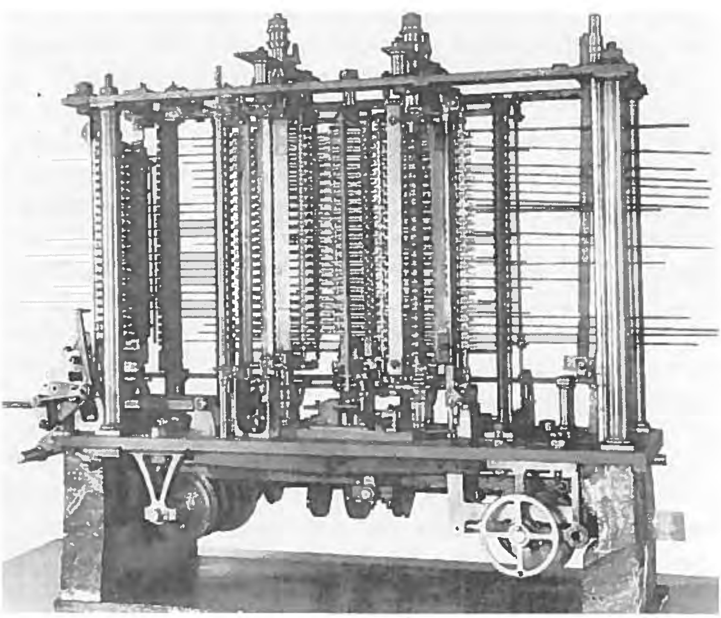
A great deal of development work is oriented toward "scaling up"—that is, making the transition from a successful research result to large-scale production. It is one thing to invent a device or process that works under laboratory conditions, and quite another to produce it in an industrial setting where commercial success is the goal. The development of penicillin provides an excellent illustration of the many facets of the scaling-up process.[11] Although the discovery of the bacteria-killing properties of penicillin initiated a major technological breakthrough, the development phase was certainly no less important.

Penicillin, a fermentation product of the mold *Penicillium notatum*, was discovered in 1928 by Alexander Fleming, who observed that bacteria were destroyed in a culture that had been accidentally contaminated by the mold. Penicillium cultures grown in small quantities were the basis of laboratory and clinical research, but this process could not yield the large quantities of the drug needed for widespread therapeutic use. Large-scale production of penicillin was eventually done in huge fermentation vats, a process that required the solution of many technical problems. The key step was the development of a submerged fermentation process that allowed the mold to be grown directly in the nutrient medium. The success of this process in turn required a number of other improvements, such as new tank designs with special cooling systems and turbine mixers, which also had to be developed. The use of corn steep liquor (a by-product of corn starch production) as a culture medium increased yields tenfold, but it created a new problem. Penicillin requires air in order to grow, but severe foaming occurred when the culture was aerated. Anti-foaming products therefore had to be developed to alleviate this problem. The extraction of penicillin from the moldy brew in the vats also created problems that were ultimately solved by the use of freeze drying, which was itself scaled up from a process first used to preserve blood plasma. As a result of all of this development work, production of penicillin had reached 650 billion units by the end of World War II, and the cost of a dose was 55 cents instead of the $20 it had been three years earlier.

All Together Now

The first chapter noted the importance of thinking of technologies as systems. This point is reinforced by a consideration of how particular technologies develop. Quite often, a technological leap forward takes place because of the availability of complementary technological developments that allow the resolution of fundamental problems. The history of the computer provides a good example of how complementary changes are essential for the translation of an idea into a workable technology. Back in the 1820s Charles Babbage began to develop an "analytical engine" that contained a set of input devices, a processor, a control unit, a memory storage, and an output mechanism—the essential elements of today's computers. But Babbage's computer was operated by an exceedingly complex set of gears, rods, and other mechanical linkages. Although he could draw on the talents of Ada Lovelace, who is often described as the world's first computer programmer, Babbage's ambitions were not fully realized for more than a century, when solid-state electronics, the cathode ray tube, and magnetic storage devices allowed the development of practical computers.

Another illustration of the importance of complementary technological changes can be drawn from the history of one of the twentieth century's most important devices, the internal combustion engine. When these engines were first produced during the late nineteenth century, the spark that ignited the air–fuel mixture was timed to occur at the top of the compression stroke. This did not allow a sufficient time for the mixture to be completely ignited, and efficiency consequently suffered. When, after much experimentation, the spark was timed to occur before the piston reached the top of its stroke, the combustion process was greatly improved, and much more power was consequently delivered. Still, early engines were deficient in power because compression ratios were kept low in order to prevent the sudden detonation of the air–fuel mixture and resultant damage to the engine. This problem was solved in part by conducting careful inquiries into the combustion process and



A portion of Charles Babbage's computer (*bottom*), which drew on the assistance of Ada Lovelace (*top*), who has been described as the world's first computer programmer. (Top photo: Mary Evans Picture Library/Alamy. Bottom photo: IBM Corporation) by reshaping the combustion chamber and piston crown in ways suggested by this research. But this was not enough. In order to employ higher compression ratios successfully, it was necessary to modify not just the engine but also the fuel it used. In particular, the research of Thomas Midgley and Charles Kettering demonstrated that the addition of tetraethyl lead to gasoline allowed higher compression ratios and a subsequent improvement in both power and economy. It was thus through a combination of cumulative improvements in both the engine and the fuel it burned that the internal combustion engine reached an acceptably high level of efficiency.

It is important to note that these changes in engine technology did not take place when the internal combustion engine was first invented, but rather during a period when it was already being sold to customers. This illustrates a point made by Nathan Rosenberg: "The idea that an invention reaches a stage of commercial profitability first and is then 'introduced' is, as a matter of fact, simple minded. It is during a (frequently protracted) shakedown period in its early introduction that it becomes obviously worthwhile to bother making the improvements."[12] In effect, consumers at times may be unwitting participants in the beta testing of new products.

The commercial viability of a new technology may thus stimulate the development of complementary technologies. A bottleneck that restricts the continued development of a particular technology creates strong economic incentives to find new technologies that clear the obstruction.[13] Many obstacles are surmounted through the use of technologies that have been developed for use by a different industry or in a different sector. This can be seen today in the automobile industry, where emissions requirements have necessitated the use of microprocessors and computers for the regulation of spark advance and air-fuel ratios. Thus, a nineteenth-century technology, the four-stroke internal combustion engine, owes its survival to its marriage to a late twentieth-century technology.

Technological advance in one area is often stimulated by the emergence of new technologies in different, but related, areas. This process can be seen in the development of nineteenth-century metal-working industries. Although their products differed substantially, the processes employed by these industries were basically the same: turning, boring, drilling, milling, and planing. At the same time, they all confronted similar technical problems of transmitting power, reducing friction, and controlling the rate of feed. This meant that a technological solution arrived at by one industry was often directly applicable to the problems of another industry.[14]

This occurred in the early automobile industry, which made abundant use of the products and manufacturing techniques that had been developed by the bicycle industry during the 1880s and 1890s. Ball bearings, spoke wheels, drive chains, and the use of electrical resistance welding had been extensively employed for the manufacture of bicycles in the decades immediately preceding large-scale automobile production. One of the most novel and significant technologies entailed the use of stamped components to take the place of forgings. Their use eliminated a great deal of machining, with a consequent lowering of production costs. The cheap, mass-produced automobile thus owed much to technologies initially developed to make a product that it subsequently eclipsed.[15]

This is hardly the only example of technologies developed by an established industry paving the way for a radically new one. Although the turbojet engine was a novel method of propulsion when it first appeared in the 1940s, it drew heavily on designs, components, and processes that had already been developed for steam turbines. In Edward Constant's summary, "All the work done on blade design, gas flow, shaft and bearing loads, temperature distribution, lubrication systems, governors, blade-cutting machines, test procedures and instruments, and countless other facets of design and production could be applied to gas turbine development."[16]

Interindustry transfers of technology do not happen automatically. The effective transfer of hardware, information, or simply (but importantly) the belief that a problem is solvable requires individuals and organizations that are capable of functioning in both worlds and have the incentives to do so. It also requires that these individuals and organizations are acceptable to the other individuals and organizations with which they interact, and that they are capable of speaking the same technical language. Technological innovation is, in Christopher Freeman's phrase, a "coupling process" that occurs at the interfaces between science, technology, and the market. This does not take place solely through intuitive flashes: "It is a continuous creative dialogue over a long period of research, experimental design, and development."[17]

Finally, it should be noted that sometimes the complementary changes necessary for the success of a new technology are not technological. A successful technological change may require changes in basic habits and attitudes. This can be seen in the failure of agricultural extension agents in New Mexico to get farmers to adopt hybrid corn in the late 1940s. There was no question about the technical superiority of the corn: demonstrations showed that its use resulted in a potential trebling of yields. Impressed by this improvement, half of the farmers planted the new variety, thereby immediately doubling their output. But after two years virtually all of the farmers had abandoned hybrid corn and reverted to their traditional low-yielding crop. The problem was that the cornmeal made from the hybrid variety could not be made into good tortillas; it did not taste right and couldn't be easily shaped. In the absence of a change in culinary patterns, a technically superior product could make no lasting impact.[18]

Push and Pull

The rejection of hybrid corn in New Mexico demonstrates the perils in the technological determinist perspective, in which technological change is viewed as a largely self-contained process. As we have seen, social constructivists have taken issue with "internalist" histories that ignore the social, economic, and political forces that shape technological change. And as was noted a few pages ago, contemporary scholarship has moved away from the "great person" approach to the history of technology. To be sure, many technologies owe their existence to the inspiration and hard work of individuals, including the unsung heroes who were responsible for the myriad improvements necessary for the realization of a new technology. But surely more is involved than their efforts. After all, human ability is presumably spread evenly throughout cultures and historical epochs, yet significant technological changes are not equally distributed over time and place. Thomas Edison's genius produced 1,093 patents, and some of his inventions transformed the world. Had he been born in ancient Rome or dynastic China, he might have helped to design aqueducts or sections of the Great Wall, but it is unlikely that his talents would have changed the course of Roman or Chinese history. Geniuses require appropriate social settings for the realization of their talents.

What kind of social system is required if inventive ability is to flourish? Why does technological innovation occur in some places and times and not in others? In beginning to answer these questions, it is helpful to apply to technological change the concepts that have been so useful to economists: supply and demand. Everything from fundamental scientific breakthroughs to minor refinements serves to "push" new technologies into the world. Still, simply having an available supply of new devices and techniques does not guarantee that they will be used. Many examples of technologies that languished because they were "ahead of their time" can be cited. The pneumatic tire was patented in 1845 and then forgotten until it was reinvented by John Dunlop in 1888. DDT was first synthesized in 1874, but it was not put to use as an insecticide until 1941. Several decades elapsed before the laser passed from being a laboratory curiosity to a practical device used for everything from supermarket scanners to instruments for microsurgery.

For a technology to make the transition from the potential to the actual requires not just that it exist; there must also be a desire for it, coupled with the ability to pay for it. Economists call this "effective demand." Seen in this light, technology is like any other good or service; it will not be produced unless some person, group, or organization wants it and is willing to buy it. Technology is "pushed" by a variety of forces, but it also has to be "pulled" by effective demand. To understand why certain technologies have flourished while others have languished, it is therefore necessary to consider the configuration of a society and the way in which it determines the effective demand for particular technologies.

The most influential research on the importance of effective demand-inducing technological change was done by Jacob Schmookler.[19] By examining a long series of patents in various industries, Schmookler found that their emergence was closely related to the level of demand for the products of these industries. To take one rather obvious example, inventors' interest in improving the horseshoe was strong when the horse was a primary means of transportation, but interest evaporated when the steam engine and the internal combustion engine began to displace it.[20]

Another illustration of the importance of demand-inducing technological development can be extracted from the history of photography in the nineteenth century.[21] For centuries painters and scientists had made use of the camera obscura, a darkened room into which light was admitted through a pinhole, resulting in the projection of an inverted image of an outdoor scene on the opposite wall. Later developments substituted optical lenses for the pinhole, which made for a sharper image. Photographs were first produced during the 1820s and 1830s when pioneers such as Niepce, Daguerre, and Fox Talbot devised chemical emulsions that preserved the image on paper or a metal plate. But the rapid growth of photography cannot be attributed simply to the supply of these inventions. At this time, social changes were sweeping across Europe, resulting in the ascendance of a new social elite, the property-owning commercial and industrial bourgeoisie. The members of this group had a keen desire to flaunt their affluence by taking on characteristics of the old aristocracy. For the latter, a key artifact of their status was the painted portrait; we have all seen renditions of persons such as the Eighth Duke of Puddleswallop hanging in our local museums. But many of the rising bourgeoisie lacked the money or the time for such symbols of their importance, and, in any event, there were not enough skilled portrait painters to serve the needs of this growing group of people. Their aspirations were therefore met by the photographic portrait studio, where the subject posed with the trappings of upper-class status, such as rich draperies and elegant furniture. In the later decades of the century, new and cheaper methods of photography emerged to meet the demands of poorer yet increasingly affluent people, such as American immigrants who wanted portraits that could be sent back home. Today, the effective demand produced by a great mass of consumers has stimulated the development of a huge variety of photographic apparatus, ranging from simple disposables to ubiquitous cell phone cameras and sophisticated digital cameras.

Good business practice is often implicitly based on the realization that successful technological development requires the presence of effective demand. One English study found that the key determinant of a firm's innovative success was an understanding of customer requirements. This meant that from its very inception,

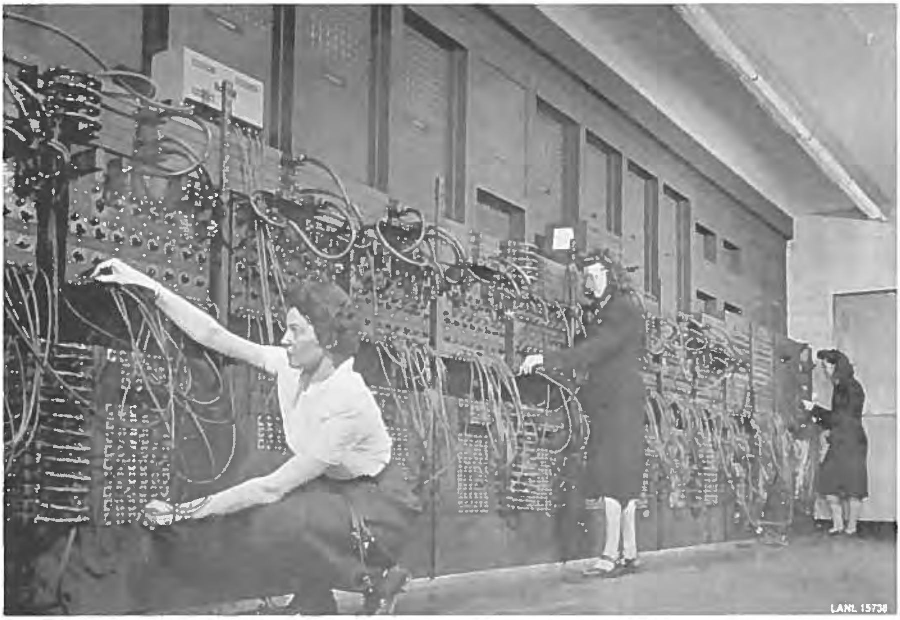
The opulent interior of a nineteenth-century photographer's portrait studio. (Alinari Archives/CORBIS) a new product or process had to be developed with an eye toward meeting the needs of actual or potential customers. Similarly, a Canadian study found that the commercial failure of many inventions was due to an inability to evaluate the true extent of demand. A great deal of product development was done with little consideration of market potential. It was often the case that entrepreneurs were so infatuated with their product innovation that they were incapable of realistically assessing opportunities and the nature of the market.[22]

Belated Demand

At the same time, however, gauging the potential demand for a new product can be a tricky task. Many of today's "essential" technologies were not at first recognized as such. When in the late 1930s Chester Carlson attempted to interest established business machine manufacturers in his photocopying device—the first Xerox machine—they were of the uniform opinion that there was no point in employing complicated apparatus and chemicals simply to replace carbon paper. And even inventors can badly misjudge the ultimate consequences of their own creations. Alexander Graham Bell initially thought that the telephone he invented would primarily be used to transmit operas and other musical performances from the concert hall to the home.[23] Edison at first believed that one of the main applications of his phonograph would be to record the last words of dying men. We can also take note of the judgment of Howard Aiken, the director of the team that built one of the world's first computers, who in the early 1950s prophesied that in the foreseeable future, the total need for computers in the United States could be met by no more than a half-dozen machines. In similar fashion, before 1950 Thomas J. Watson, the president of IBM, was of the opinion that there would be no commercial market for computers.[24]

The history of radio also shows how a technology may be put to uses not envisaged by its inventors. When equipment for sending and receiving radio waves was first developed during the late nineteenth century, no one imagined that it would be used for commercial broadcasts. The first transmitters and receivers were devised for purely intellectual purposes—in order to test the validity of James Clerk Maxwell's theories about the nature of electromagnetic waves. Only after the passage of more than a decade did some visionaries perceive a commercial use for radio apparatus, and then their imaginations were limited to the use of the radio for ship-to-shore communications. Decades passed before the idea of broadcasting to a mass audience emerged.[25]

What are we to make of these examples? They seem to refute the theory that technologies are primarily the result of "demand-pull," for all of the technological developments just described emerged in the absence of apparent demand for them. Perhaps we can salvage the demand-pull theory by distinguishing two different kinds of technological advances. The first kind consists of refinements and improvements to an existing way of doing things, while the second (and far less frequent) is the truly revolutionary breakthrough—the Internet, the digital computer, radio, the telephone, and the like. In cases such as these, the very novelty of a revolutionary breakthrough makes it difficult to determine what its ultimate uses will be and



ENIAC, a first-generation electronic digital computer, was programmed by plugging and unplugging cables. (CORBIS)

who, if anyone, will want it. By contrast, advances of the first kind occur within a known context; the basic technology is already in use, and there are likely to be people and business firms that want, and are willing to pay for, the new wrinkles that promise to improve an existing technology. Improvements of this sort therefore have a predictable market. Conversely, radically new technologies confront a great deal of uncertainty. They may satisfy a latent need, or they may create a new one. They may also sink without leaving a trace. They are flights into the unknown, and it is hazardous to guess what sort of a reception they will meet. If nothing else, they confirm the old Chinese saying that it is dangerous to make predictions—especially about the future.

Market Economies and Technological Advance

The forces that "push" and "pull" technological advance do not exist everywhere or in equal measure. In many places and at many times, the distribution of wealth and power retarded these forces, resulting in a slow pace of technological advance. Moreover, the particular technological advances that do occur usually reflect a society's general configuration of wealth and power. In the European Middle Ages, the landowning aristocracy and Church officials controlled most of the wealth and wielded great power. The monastic orders often played an important role in land clearing, farming, and the construction of mechanical devices, but for the most part the religious and secular establishment showed little interest in such matters. While the era gave rise to significant technological advances in water power, mechanical clocks, and weaponry, its most evident technological triumph was the great symbol of the traditional order: the Gothic cathedral.

As European history unfolded, the interests and demands of a growing merchant class led to the development of technologies that eventually surpassed even the soaring cathedrals. The great technological innovations that began in the mid-fifteenth century with improvements in shipbuilding and ocean navigation were closely associated with the rise of capitalism and the emergence of a market system. A market system organized around the principle of private property was of crucial importance for the stimulation and guidance of inventive and innovative abilities, as well as their application to production.[26]

One of the strongest accolades to the technological dynamism of capitalist society can be found, of all places, in *The Communist Manifesto*. With unfeigned admiration, Karl Marx and Friedrich Engels note that the following:[27]

> The bourgeoisie, during its rule of scarce one hundred years, has created more massive and colossal productive forces than have all preceding generations together. Subjection of Nature's forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric telegraphs, clearing of whole continents for cultivation, canalisation of rivers, whole populations conjured out of the ground—what earlier century had even a presentiment that such productive forces slumbered in the lap of social labour?

In the time of Marx and Engels, and in our own time, a market economy driven by the activities of self-interested businessmen has produced the most receptive environment for technological innovation. There are several reasons for this. A market economy will stimulate inventive efforts, for it promises financial rewards to those able to meet the needs of consumers. For example, somebody invents a better mousetrap in the hope of selling it in the market. If the demand is there, eager customers will buy it. Everybody is better off: consumers have a better mousetrap, while the inventor gets rich and retires to Palm Springs, and nobody worries about how technological advance has lowered the quality of life for mice. Second, a market economy is characterized by the presence of numerous competitors. Under these circumstances, a producer is strongly motivated to develop and apply new technologies in order to make better products and to reduce production costs. Failure to do so may result in the eventual collapse of the enterprise, as the history of many once-successful firms demonstrates. Finally, a market system is particularly effective in eliciting the production of the auxiliary items necessary for technological innovation. A new technology will require special materials, components, and services. Because of its responsiveness to new sources of demand, a market economy is well suited to meet these requirements.

The advantages of a market economy in stimulating technological advance are further demonstrated by an examination of centrally planned economies. For decades the economies of the Soviet Union and the People's Republic of China were organized through the mechanisms of central planning, but during the 1980s it became painfully evident that these mechanisms were fatally flawed. One of the chief manifestations of that failure has been a retarded technology. It cannot be denied that the Soviet Union produced some impressive technological achievements, most notably in its space and military programs, while China made significant progress in industrializing an impoverished country, but taken as a whole their level of technological development remained stagnant while the United States, Western Europe, and Japan moved rapidly forward.

The backwardness of centrally planned economies has had significant political repercussions. In China, dissatisfaction with the pace of technological and economic advance led to a retreat from centralized planning and a much greater scope for market-based economic relations, In the Soviet Union, the fear of falling even further behind the West motivated the Gorbachev regime to introduce some elements of a market economy and to attenuate the role of central planning. But these efforts were not enough, and within a few years the Soviet Union ceased to exist. In the countries of the former Soviet Union and in China, it has become evident that market-based reforms have made major contributions to economic and technological development, albeit at the cost of greater economic and social inequality, as the recent histories of the two nations have shown.

Many of the difficulties experienced by centrally planned economies in achieving technological advance have been the result of a basic tension between their system of economic management and the requirements of technological innovation. Centrally planned economies rest on the assumption that economic activities can be reduced to predictable routines. But the course of technological innovation is notoriously difficult to predict. The bureaucratic procedures that work tolerably well for the administration of routine productive tasks usually fail when they are applied to technological innovation. A planning agency can set goals and quotas for the production of established goods, and various ministries can oversee the actual operation of individual enterprises through routine bureaucratic administration. But these procedures work much less well when innovation is the goal. Innovation is an activity full of risk and unpredictability, and it cannot easily be accommodated to preprogrammed structures and activities.

To make matters worse, centrally planned economies attempt to motivate workers and managers through the allocation of rewards that create disincentives for technological innovation. A factory manager typically receives bonuses for the fulfillment and overfulfillment of quotas for established products, as given by the central plan. The production of an innovative product is not rewarded, for it has not been stipulated by the plan. The uncertainties and unpredictabilities that surround technological innovations create risks for those who seek to develop and use them, but these risks are not matched by commensurate rewards for those who take them.

Noneconomic Sources of Technological Advance

It is not the intention here to convey the impression that only market forces can produce technological innovation; as we shall see, government institutions have become increasingly important sources of technological advance. And no inference should be made that the historical superiority of a market economy in promoting technological advance makes it a superior system in general. There is more to life than technological advance, and, as we have already seen and shall see some more, both capitalism and the market have produced technologies that have been detrimental to large numbers of people.

Furthermore, technological innovation cannot always be traced to economic motives or even to the desire to address practical problems. To be sure, we tend to think of technology as the result of efforts to solve problems of this sort; after all, technology has already been defined as the product of knowledge that is used in order to get something done. The very word "technology" conjures up images of useful devices, and technology's practitioners—engineers, managers, and skilled workers—are often viewed as a serious bunch, sitting rigidly in front of computer terminals, making precise measurements, and, above all, applying their talents to the solution of practical problems that are usually tied to economic concerns.

In fact, even the most practical of inventions may owe their origins to a spirit that seems more closely connected to play than to "productive" work. When Willis Whitney served as the first director of the research laboratory of the General Electric Company, he often asked his scientists and technicians there if they were "having fun." For Whitney, "fun" was working on problems that had stumped everyone. Pursuing these problems was nothing less than the most exciting thing that a person could do.[28]

Consider, too, one of America's most famous inventors, Benjamin Franklin. With typical American pragmatism he wrote, "Utility is in my opinion the test of value in matters of invention, and that a discovery which can be applied to no use, or is not good for something is good for nothing."[29] Franklin's inquiries into the nature of electricity did result in one useful device: the lightning rod, which saved many a building from destruction. But his other inquiries had a less immediate payoff. Although Franklin devised a number of devices that helped him to learn more about the nature of electricity, decades passed before electricity had any practical value. Indeed, he was "chagrined a little that we have been hitherto able to produce nothing in this way of use to mankind."[30]

Later events proved him wrong, although he never shared in that knowledge. Still, the pursuit of useful innovations could not have been the prime motive for Franklin's inquiries. Franklin was an amateur in the literal sense of the word: a person who pursues an activity for the sheer love of it. For many years the leisure-time pursuits of amateur scientists such as Franklin sustained research into the nature of electricity despite the absence of direct applications, yet these "idle" intellectual efforts were essential to the invention of a great variety of useful devices.

A century after Franklin died, a young man of seventeen climbed a cherry tree and turned his imagination to possibilities that only a few had dreamed of. The year was 1899, and the young man was Robert Goddard, who was to be the inventor of the liquid-fueled rocket. As he recalled in later years, "It was one of the quiet, colorful afternoons of sheer beauty which we have in October in New England, and as I looked toward the fields at the east, I imagined how wonderful it would be to make some device which had even the possibility of ascending to Mars, and how it would look on a small scale, if sent up from the meadow at my feet. . . . I was a different boy when I descended the tree from when I ascended, for existence at last seemed very purposive."[31] At that time, and for many years to come, Goddard could scarcely have imagined the products of that October vision: orbiting satellites for global communication links, weather prediction, global positioning systems, and the development of terrifying new weapons. Throughout his life Goddard continued to be energized by the dream of space travel for its own sake; practical consequences were at best a secondary concern.

It also should be noted that even in a predominantly market-oriented, capitalist society such as the United States, not all technologies have been generated and shaped by market forces. Chapter 18 will take up this issue by examining the role of the government in promoting technological change. At this point it will only be noted that technologies developed outside the constraints of the market system are less likely to be shaped by concerns about costs. Firms operating in a market

The realization of a vision: Robert Goddard and his first liquid-fueled rocket. (UPI/Bettmann Newsphotos) environment know that minimizing costs is essential to success. Technologies that hold down production costs are quite appealing, as are technologies that expand sales by lowering the cost of the product itself. The Ford Motor Company during the glory years of the Model T is a striking example of a firm that owed its success to the use of new technologies in order to lower costs. This process also has been dramatically demonstrated in recent years as technological advances in the design and production of integrated circuits have led to sharp declines in the price of personal computers and a concomitant expansion of this market. At the same time, however, there are large sectors of the economy where prices and the costs of production are secondary concerns. As a result, the pattern of technological development can be quite different. This has been particularly evident in the defense industry, where the presumed dictates of national security have allowed the deployment of staggeringly expensive military technologies. To take a particularly striking example, a single Air Force F-22 fighter costs U.S. taxpayers $412 million (when R&D and testing costs are taken into account) and requires 30 hours of maintenance and an expenditure of $44,000 for every hour it is in the air.[32] In a climate where only the presumed best will do, there are strong tendencies to "gold plate" weapons systems and to have little concern for cost constraints.

This tendency is not confined to the military sector. In recent years there has been a mounting concern about the financial costs of modern medical technologies. Some medical technologies, such as antibiotics, have undoubtedly lowered the costs of medical care, but many others have had the opposite result. When faced with a choice between controlling medical expenses or saving lives and alleviating pain through the use of sophisticated technologies, it is difficult for any individual or society concerned with the well-being of its members to put the former ahead of the latter. It is thus no surprise that about half the growth of health care spending that occurred during the second half of the twentieth century can be attributed to the use of new technologies.[33]

The case of military and medical technologies brings us back to the necessity to consider the political and social context of technological choice. Economic considerations, important as they are, are not the sole basis of decisions regarding the development, selection, and use of particular technologies. Nor does technology develop according to its own internal dynamics. Technologies are social creations, and any successful attempt at understanding why particular technologies are created, chosen, and used must take into account their social context. Having made this basic point, we will pursue the matter a bit further by looking at the processes through which technologies spread and take hold. But before we do so, we need to consider one more source of technological change: scientific advance. This will be the topic of the next chapter.

Questions for Discussion

1. In your opinion, how well does the social construction approach explain technological innovation? What technologies seem well-suited to the application of this perspective? Which do not?

2. In times past, inventors like Edison, Morse, Tesla, and the Wright brothers were treated as celebrities. Can you name any contemporary inventors? Why do individual inventors appear to be less prominent today?
3. A person with a heart problem needs a pacemaker but is unable to pay for it. What, then, is the source of effective demand for this technology? Who ultimately pays for it, and why?
4. As a would-be inventor or entrepreneur, how would you go about ascertaining whether or not a new technology is likely to find a receptive market?
5. If you were the leader of a developing country, what sort of changes would you try to institute in order to accelerate the pace of technological innovation?

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