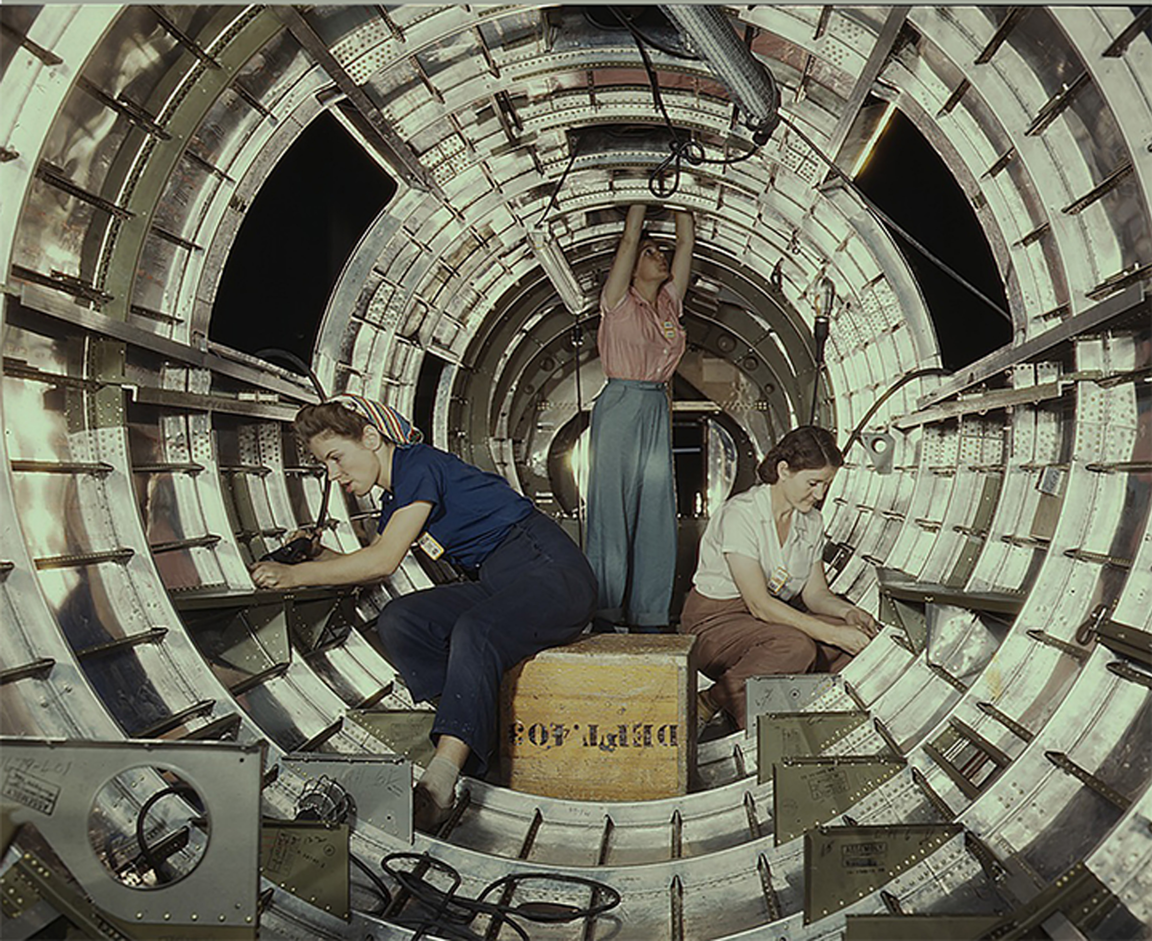
TECHNOLOGY AND AMERICAN SOCIETY

THIRD EDITION

GARY CROSS
and RICK SZOSTAK

ROUTLEDGE



Technology and American Society

Providing a global perspective on the development of American technology, *Technology and American Society* offers a historical narrative detailing major technological transformations over the last three centuries. With coverage devoted to both dramatic breakthroughs and incremental innovations, authors Gary Cross and Rick Szostak analyze the cause-and-effect relationship of technological change and its role in the constant drive for improvement and modernization. This fully updated 3rd edition extends coverage of industry, home, office, agriculture, transport, constructions, and services into the twenty-first century, concluding with a new chapter on recent electronic and technological advances. *Technology and American Society* remains the ideal introduction to the myriad interactions of technological advancement with social, economic, cultural, and military change throughout the course of American history.

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Technology and American Society

A History

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By Gary Cross and Rick Szostak

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Preface

This book is about the interaction of American technology and society from colonial times to the present. Despite the constraints of space, we have taken a very broad view of technology. We look not just at innovation in industry, but in home, office, agriculture, transport, construction, services, and media. We consider both the causes and effects of technological change. While we organize chapters chronologically, we are not slaves to a year-by-year chronicle of events. Rather, each chapter provides a comprehensive and integrated treatment of a particular technological trend. The time spans addressed in particular chapters therefore overlap and vary in length.

While we necessarily isolate themes, we recognize the interdependence of technological advances. The modern automobile is not only a result of improvements in the internal combustion engine but is dependent also on new factory machinery and work organization as well as sophisticated electronics and plastic components. We also emphasize that, while the course of technological change appears inevitable, with hindsight, innovation is of necessity fraught with uncertainty. Innovators face many different paths that they could pursue. Often, competing technologies achieve some degree of commercial success (AC versus DC electricity, steam versus electric and gasoline automobiles. for example). A host of cultural, economic, legal, and psychological factors may determine which innovative path prevails. Sometimes, as in the layout of the typewriter (and later computer) keyboard, which places some of the most common letters off to the side, decisions made early in the innovative process determine the course taken. Thus, even when the original need (in this case a key layout designed to avoid the clash of mechanical parts) no longer applies, we retain the old keyboard layout. This is called 'path dependence.' It is precisely because the course of technological change is far from inevitable that we devote space to discussing why particular choices were made. We have endeavored to show that technology and society continuously interact rather than that one determines the other.

We should not leave the impression that all technological decisions were made by private individuals. The government did much more than set the rules. Its role in military technology was ubiquitous, and there were often civilian spillovers. Agriculture, transport, and health were other areas in which governments directly encouraged innovation. From the twentieth century, government support of science has aided technological advance across a wide range of applications.

We also believe that we cannot examine American technology in a vacuum. While the United States has been a technological leader across many fields for much of the last century, this has not always been the case. Much of American technological advance in the eighteenth and nineteenth centuries involved borrowing European technology—even as Americans have adapted these innovations to their own conditions. Only by placing American technology in a global context can we hope to understand the waxing and waning of its technological leadership. Space alone has prevented us from paying proper attention to the impact of American technology on the rest of the world.

Perhaps the most central feature of our book is our effort to link innovation with social change. Historically, technology has always produced winners and losers, proponents and opponents of change. Machines have repeatedly displaced skilled crafts people, and many critics have objected to the pollution, military uses, lifestyle changes, and aesthetic effects of new technology. The course and rate of technological change were and are conditioned by the distribution of power in society. Who finances innovation? With which sections of society do innovators identify? Does the legal environment favor the status quo or change?

We have paid special attention to the links between technological innovations and changes in gender roles in American society. Technology has shaped the lives of women and men both in and outside the home. It has shaped decisions of men and women to abandon domestic production for work in factories and offices. Yet innovation alone did not shape social roles. Cultural expectations (e.g. prevailing ideologies of 'a woman's place is in the home') affected how technologies would be developed (e.g. a heavy stress on developing domestic appliances).

Throughout American history, citizens have varied greatly in their attitudes toward technology. While the majority perhaps have tended to view innovation as a generally benevolent force, substantial numbers of American have become conscious of the negative effects of innovation—especially in the last century. These conflicting attitudes and their origins are also a part of our story.

The authors of this book met at a conference at the University of New South Wales two decades ago. We hope that we have each brought out the best in the other. While both authors take interdisciplinary approaches, one has focused on the socio-cultural questions and the other, the economic problems raised by our topic. Together, our previous research has spanned most of the time period under study. We have often been each other's harshest critics. Gary Cross is primarily responsible for Chapters 1–2, 6–8, 11, 15–17, and 20 and Rick Szostak for 5, 9, 10, 12–14, 18, and 19. We divided Chapters 3, 4, and 21. Nevertheless, we have ensured that the text flows smoothly from chapter to chapter. Co-authorship is the greatest test of friendship, and we are pleased to confirm that ours has survived intact.

In fact, it has prevailed despite distance and time enough for us to write a third edition. We have attempted to update the book with a thorough review of new literature and a systematic effort to improve the accuracy and prose of the second edition. We have also recognized the need to add new material on topics such as GPS and artificial intelligence and to reorganize our coverage of the automobile and media. We hope that our readers enjoy reading the book as much as we enjoyed writing it.

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1 Working the Land in Preindustrial Europe and America

Americans often hold conflicting images of technology and its role in the history of the United States. In particular, many people look nostalgically upon the world before factories and mega-cities as a time of harmony with nature, close-knit communities, and hard but satisfying work. This romantic impulse to critique the modern world by finding a lost paradise in the past has been a common response since the beginnings of industrialization. Others adopt an opposite response that is equally as old. These 'modernists' see the traditional world as insecure and, for the vast majority, impoverished, requiring unrelenting labor to survive, and making people paranoid and superstitious.

These differences reveal contrasting feelings that many of us hold about the modern world. The romantic view of traditional society has often pointed to the human costs of modern technology: the loss of the beauty of nature, the decline of personal contact with familiar faces, the disappearance of the joy that came from making things from scratch, and the loss of a seemingly natural pace of life. Craft historian Eric Sloane (1955) offers such a romantic image of the colonial landscape: "Close at hand there were lanes with vaulting canopies of trees and among them were houses with personalities like human beings. At a distance, it was all like a patchwork quilt of farm plots sewn together with a rough black stitching of stone fences. But the advance of 'improvements' has done blatant and rude things to much of this inherited landscape."[1]

By contrast, the modernist sees technological progress as the harbinger of greater personal comfort and security, the herald of both individual freedom and greater economic and social equality, and the vehicle of human creativity and sheer wonder. Most of us probably agree with a bit of both perspectives—although we may lean one way or another. The task of the historian, however, is to try to go beyond these romantic and modernist ideologies and to present a subtler—and, hopefully, more accurate—picture of how technology has shaped American society today. And to do this we must begin with how Americans worked and coped with their environments before modern machinery and technology.

In order to understand this old world of American technology, we must recognize its origins in the Old World of Europe. Not only did European settlers in North America bring with them technologies and patterns of work that they had known in the Old World, but long after they had arrived, immigrants and their children continued to rely on European methods of farming and manufacturing. With notable exceptions, settlers depended upon European technological innovations during early industrialization. In the 1790s, Samuel Slater of Rhode Island copied British textile machinery rather than inventing something new. At that time, Europeans and many Americans considered the New World to be a technological backwater, from which Europeans could expect only to obtain raw materials like cotton and wood for their industrial needs. North America was bound to be a land of inferior manufactures fit, at best, for local consumption. Only after 1800 did Americans begin to change this dependence upon Europe. Even then, innovation was often a transatlantic phenomenon. The history of technology in the United States cannot be isolated from that of Europe.

Yet, Americans deviated from European antecedents. From colonial times, settlers encountered vastly different physical conditions from those of Europe: distinct and unfamiliar topography, water, mineral and soil resources, and climatic conditions, for example. Colonists learned from native peoples how to adapt to this strange new environment. And settlers represented a self-selected migration of Europeans with particular expectations and skills. These factors led to unique paths toward economic growth and innovation in the New World. Yet, the colonial economy was also hampered by a scarce and scattered population that greatly encumbered the task of finding suitable workers or reaching markets. These unique opportunities and challenges meant that Americans followed particular avenues toward modern industrialism. Nonetheless, Americans are often too prone to overemphasize their heritage of exceptional 'Yankee Ingenuity.' If we recognize the legacy and linkages with Europe, we can better understand why, when, and to what extent Americans differed from (and sometimes led) the wider world in technological innovation.

Crops, Animals, and Tools: European Antecedents

We must begin our survey of technological change in American history with a brief overview of its origins in European agriculture. At its heart was the cultivation of grain—especially rye, oats, barley, and, of course, wheat. Rice was grown in parts of Italy (and by the end of the seventeenth century in the Carolinas), but rice was considered only an emergency food to feed the starving poor. The range of vegetables in Europe was narrow: The English grew various dry peas and beans, turnips, and parsnips, which supplemented grains, provided cheap protein, and could keep long periods. Farmers, however, did not specialize, growing most of what they consumed themselves. And they had to cope with insect and fungal outbreaks that often led to sickness. Europeans in general were peoples of grain. Around the cultivation of these cereal crops were built technologies of planting, plowing, harvesting, storing, milling into flour, and even transportation, requiring a wide variety of cereals and vegetables to be planted.

Europeans were also meat eaters. In the 1200s, while China was building a civilization based on biannual harvests of lowland aquatic rice, medieval European aristocrats were feasting on beef, pork, and fowl. Even the poor occasionally enjoyed the protein of meat and more frequently of cheese. Europeans were thus likely healthier and stronger than others with a more monotonous diet. But this 'privilege' was paid for at a high price: Meat production was an inefficient source of calories, placing severe limits on European population growth. China's intensive use of land in rice cultivation made possible a large population, whereas Europe's 'waste' of scarce land for animal pasture and grain for fodder reduced the potential size of families.

Wheat was inefficient when compared with the rice technology of Asia or the corn (or maize) agriculture of Mesoamerica. Between the fourteenth and seventeenth centuries, for every three to seven grains of wheat harvested, one grain had to be set aside for the next year's seed. By contrast, each maize seed (or corn) produced 70 to 150 grains in seventeenth-century Mexico. By comparison today American wheat fields yield 40–60 times the seed sown. Old World wheat also depleted soils rapidly unless land was regularly allowed to recover, by periodically leaving fields unplanted. This fallow land was often tilled to aerate the soil, fertilized with manure, and allowed to regain vital salts. Animals and grain competed for land and this probably encouraged Europeans from the fifteenth century to seek virgin soils in the temperate climates of the Western and Southern Hemispheres, including what became the United States.

Of vital importance was the 'Columbian Exchange' of plants and animals that began with European landings in the New World. European explorers were quick to see the advantages of 'Indian corn,' with origins in the American Southwest and widely cultivated by indigenous people. Sugar, a rarity in the diet of medieval Europeans, became a very profitable import from the West Indies and Brazil by the end of the seventeenth century, resulting in the mass enslavement of Africans for labor on sugar plantations. Of equal importance was tobacco from the Caribbean that was first introduced to Europe by the Spanish soon after Columbus's arrival. It became the cash crop of Jamestown Virginia colonists in the early seventeenth century. Until the eighteenth century, European farmers resisted another New World food, the tomato, some fearing that it was poisonous. Only with considerable ingenuity (much by American farmers and cooks) did it become a staple in salads and pasta on both sides of the Atlantic. The potato, another New World food, originated in the Andes of South America. Though it was brought to Europe around 1660, peasants resisted its cultivation until the 1790s when it fed a growing population of poor farmers. This modified stem that grows underground was originally toxic, but the Andean Indians gradually bred safe varieties. Potatoes were critical to European peasants: They could be harvested in three months before grain matured. Dependency on the potato crop would lead to the Irish Famine in the 1840s, when disease struck that vegetable. Also, important exports from the Americas were sweet potatoes (very important to China), pumpkin, and many types of beans (Figure 1.1).

The Columbian Exchange of foods between Europe and the Western Hemisphere also went from east to west: Europeans brought pigs, sheep, cattle, and horses to the New World as well as wheat and rice. Pigs reproduced and matured quickly, and cattle could feed on grass (inedible to humans), providing not only dairy and meat, but leather and much else to the early colonists. Horses, first brought by the Spanish in the sixteenth century, were critical for the European colonists, but they also transformed the lives of the native peoples of the Plains.

Despite the inefficiency of European agriculture and the slow adoption of New World crops in the Old, European agriculture had many advantages that would give Western culture an edge over the East (and the indigenous peoples of the Americas). Animal husbandry was essential to Western civilization; it provided not only protein, hides, and fiber for clothing, and fertilizer for farming, but labor-saving work. Wheat farming generally required draught animals, especially the horse and the ox, to plow and harrow land. Although water buffalo and horses were available in China and India, they were relatively rare

Figure 1.1 An English lithograph by John Hinton (1749) of a West Indies sugar plantation and slaves crushing and boiling the cane.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

in the rice paddy. An eighteenth-century observer claimed that seven men were required to pull as much weight as could a horse. And the horse gave Europeans (and others) mobility for trade and conquest. By the seventeenth century, animal breeding had produced highly specialized horses for work, racing, and other purposes. Perhaps by 1800, there were 14 million horses and 24 million oxen in Europe. Animal power saved much human labor even though land had to be devoted to feeding.

Another Western advantage was the prevalence of wood and its products. Northern European civilization emerged out of the forests. These people depended on wood for heating and cooking fuel, housing construction, most machinery (including waterwheels and even clocks), ships and wagons, and even the fuel necessary for the smelting and forging of metals. Wood was an ideal raw material for a low-energy civilization: it was easily cut, shaped, and joined for the making of tools; it was stronger, lighter, and more malleable than stone for many purposes; and it could be cheaply transported by floating on water.

However, wood was flammable and inefficient as a fuel. It lacked durability and tensile strength, especially as moving parts in machines, or as cutting or impact tools like plows or mallets. An even greater problem was deforestation, making coal a viable alternative to wood as a heating and smelting fuel. Especially after 1590 in England, ordinary wooden buildings were replaced with brick and stone. Still later, iron would be substituted for wood in machine parts and other uses, but this took a long time. Shortage of specialty wood in the seventeenth century, especially for boat masts, caused Europeans to seek new sources in New World forests (Figure 1.2).

European civilization and its American outposts were built around grain, animals, and wood through the eighteenth century. Essential to agriculture were simple wooden tools: The plow, harrow, sickle, flail, and millstone were all known in ancient Egypt and Rome. Oxen or horses pulled the plow, a fairly complex tool that dug into the soil to cut and turn over furrows, thus aerating the soil for seeding. Fields were first sliced vertically by the plow's sticklike coulter, which was followed by the share, which made a horizontal cut beneath the furrow slice. Behind the share was a broad moldboard that was set at an angle to turn over the furrow and to bury the old stubble. Nevertheless, peasants on small farms continued to use hoes, spades, or hand-held breast plows until the end of the eighteenth century.

Next, the farmer used a harrow. This tool often consisted of a triangular or rectangular frame studded with pointed wooden sticks. Harrows were dragged across previously plowed land to clean out weeds, pulverize cloddy soil, and smooth the surface for planting. Seeding was often done by simple broadcasting. Increasingly, however, from the seventeenth century, farmers adapted the less wasteful (if more time-consuming) method of dibbling. This was a process of depositing seed in a hole 'drilled' by a handheld pole with a pointed end. This allowed for more uniform row planting and eased the time-consuming task of weeding.

Harvesting grain likely created the greatest problems for farmers. Nothing was more critical than cutting or reaping the plant and threshing or separating the grain from the plant head. Reaping was a very time-consuming activity. Especially with wheat, there were only a few weeks to get this job done before the grain shriveled or dropped to the ground to be wasted. The threat of rain or wind always made this job more urgent. Until the eighteenth century, the

Figure 1.2 Mid-eighteenth-century plowing (figs. 1–3), seeding (figs. 4, 5), harrowing (fig. 6), and rolling (fig. 7).

Credit: *Diderot's Encyclopedie, 1771.*

curved blade of the sickle remained the almost universal tool for cutting stalks of grain. Equipped with a sickle, a worker could reap about a third of an acre per day.

Helpers gathered the stalks on the ground into shocks for easier shipment to the barn for later threshing. Threshing was often done with a flail—a simple tool composed of a long handle (or staff) to which a shorter club (the swiple) was loosely attached with a leather cord. The thresher simply laid harvested grain stalks in a line across a barn floor. The farmer then beat the heads with the swiple until the grain had separated and the straw could be swept away. The remaining grain had to be winnowed, blowing away the straw or chaff still attached to the grain. This was often done simply by tossing basketfuls of the grain and chaff mixture into the wind, hoping that the light chaff would be carried away and that the grain would fall 'clean' back into the basket. One person could thresh and winnow about seven bushels of wheat this way in a day. On larger farms, oxen or horses 'treaded' upon the wheat heads. This increased the speed of threshing about fourfold; there was a price to pay, however, in crushed and wasted grain. In any case, threshing could easily take weeks in the winter months.

The job of harvesting corn was less pressing, for this grain could stay on stalks in the field until early winter. But this too was no easy task: The ears of corn or stalks (for feed) had to be cut by hand. An equally laborious task was husking and shelling' corn (a term perhaps derived from the colonial American practice of using seashells to strip the kernels from the cob).

Though farm work was often sun-up to sun-down, it varied with the season (Figure 1.3 and 1.4). In colonial New England, the farmer's yearly cycle began in late March with the draining, plowing, and harrowing of the fields, followed by planting. A lull allowed the farmer to repair tools and fences, to clear land, and to shear sheep. By late May, the haymaking season began. In the next lull in field work, cheese was often made (women played an important role in this craft). Grain was harvested from early August to October along with root crops like potatoes. Autumn was the time of the most intense and lengthy work-days. The harvest required the hands of as many laborers as possible, including children, women, and even the rich. Once these crops were harvested, the remaining weeks before the winter freeze were used to pick and process fruit (especially apples) and vegetables, and slaughter animals for food.

The seasonal cycle of work, of course, varied with the crop and climate. Southern American staple crops like tobacco, cotton, and rice naturally required an entirely different set of tasks and organization of labor, one of the many reasons that slavery was adopted. Tobacco, for example, necessitated great care in all parts of production. This encouraged planters to adopt a system of closely supervised gang labor. By contrast, on cotton plantations there were long periods of relative inactivity (between December and March, and during the summer, before harvesting). This allowed planters to leave their estates in the hands of foremen or even trusted slaves. Labor-intensive agriculture discouraged mechanization and innovation in the South until after the Civil War.

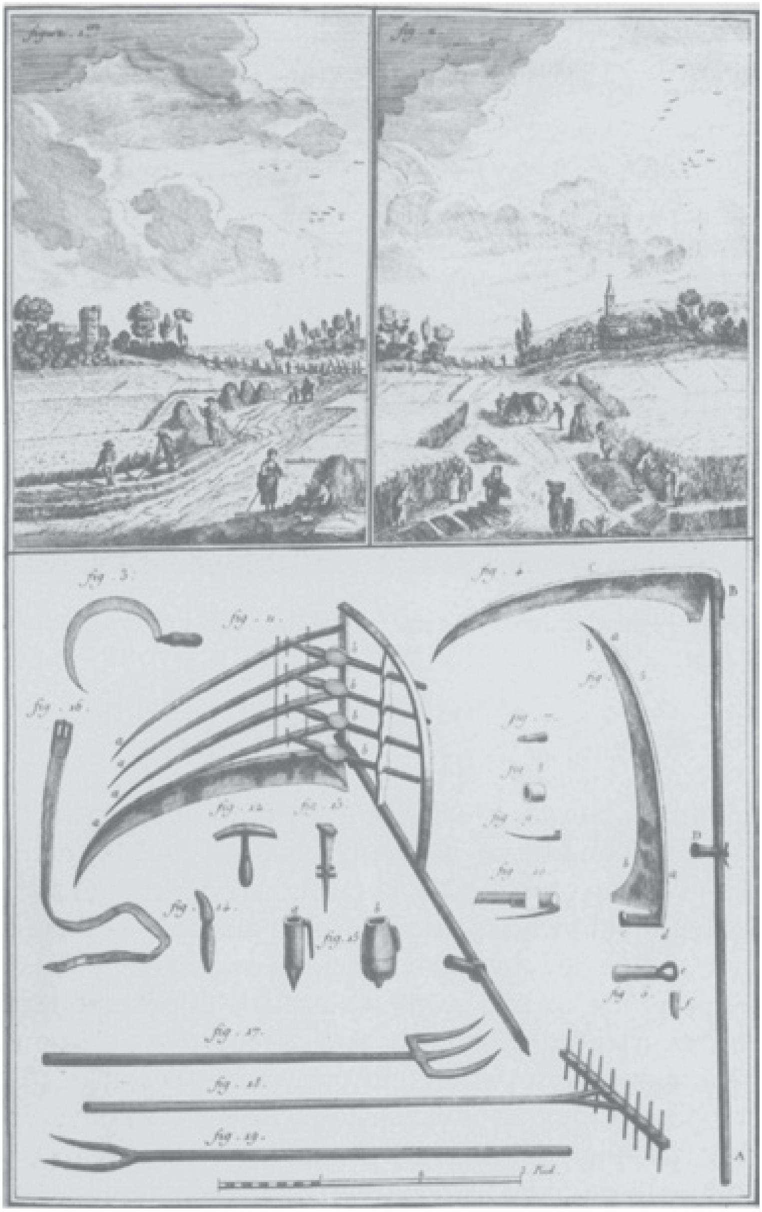

Figure 1.3 Harvesting tools, including the sickle (fig. 3), scythe (fig. 4), and an eighteenth-century French mowing device similar to the later American cradle (fig. 11). Note the women in the fields.

Credit: *Diderot's Encyclopedie, 1771.*

Figure 1.4 Threshing scene in an eighteenth-century barn. Note the use of the flail (fig. 3).
Credit: *Diderot's Encyclopedie, 1771.*

Despite the long hours of field work, farmers supplemented their income in many ways: In America, they trapped and hunted animals for meat or fur; more importantly, they lumbered and produced wood by-products. Some were part-time miners. In both Europe and the northern colonies, farmers' families often worked in their homes spinning yarn or making shoes, nails, or cheap furniture. In an economic organization often called the 'putting out system,' rural workers relied on materials supplied by traveling merchants, who also would gather the completed work for sale in the market.

Seasonal lulls allowed English farmers to participate in traditional religious and folk festivals: Common holidays were Shrove Tuesday just before Lent, Good Friday, Whitsun week or Pentecost, Midsummer on 24 June, Michaelmas on 29 September—and, of course, Christmas. Some of these traditional European festivities died out in colonial America. But colonial farmers shared in breaks for fairs, group hunting trips, elections, and religious revivals. Most importantly, weather and season, rather than machine or even market, dominated the pace and character of work.

Consequences and Causes of Low Agricultural Productivity

Preindustrial farm life doubtless had its charms. Yet, while colonial American agriculture produced sufficient food to allow a rapid expansion of population, this was the exception. In Europe, farmers were terribly constrained by the relatively meager harvest. Because of the low productivity of Western grains, slight decreases in the harvest could have devastating effects. Unusually wet summers and cold winters, like those common in Western Europe in the 1690s, meant repeated crop failures. Yields that produced food grain-to-seed ratios of 4:1 had only to fall to 3:1 to mean serious shortages for the poor. Meager harvests led to catastrophic increases in bread prices that soaked up 90 percent of poor people's income or more; in towns, this typically depressed craft industries, for common people had little income left for shoes or cloth. In crises, the poor also shifted to secondary cereals—buckwheat or rye—or subsisted on soups and breads made of chestnuts. The poor in backward portions of Europe were reduced to eating thin gruel and soups; bread was baked as infrequently as every two months, and it was so hard that it sometimes had to be cut with an axe.

Over the seventeenth and eighteenth centuries, yield-to-seed ratios in most areas of England and the Continent rose to approach 10:1, due to new crop rotations and other advances. Improved transportation also reduced famine in regions suffering from crop failure. Still, grain supplies governed economies and the stability of governments on the European continent until the middle of the nineteenth century.

Cultivation of grains, we should note, allowed for a far denser population than ever possible when people hunted animals and gathered vegetables, fruits, and seeds. Anthropologists estimate that on the eve of the era of farming—about 10,000 BCE—there were no more than 20 million humans on earth. By 1750, on the eve of modern industrialization, there may have been as many as 750 million people. Throughout their history, agricultural societies commonly grew at 0.5 to 1.0 percent per year.

But such growth was regularly checked by the grim reaper of famine and disease: In a single spring and summer following a poor harvest, death rates could rise from the range of 30 to 40 per 1000 to 150 or even 300. From 1347 until the 1720s, diseases like the plague and cholera regularly visited villages and cities. And, despite their access to food and what passed for 'medicine,' the rich and powerful did not escape. For example, the famine and plague years of 1628, 1635, and 1638 (combined with war) caused a loss of a quarter of the central European population. This historical reality was summarized in Thomas Malthus's observation that limited food supplies always checked population growth.

Famine particularly touched the young, pregnant and nursing mothers, as well as the frail. Even in 'normal' times, 20 to 30 percent of infants often did not survive the first year. At the same time, death was as likely to claim as large a portion of people in their twenties as it does today of people in their sixties. This reduced the portion of the population in the most productive years of life. Preindustrial European society was dominated by the very young: From a third to as many as half of the population were under the age of 15. The low level of productivity simply did not allow these people the luxury of play-filled childhoods. Children had to work.

For the same reason, few could live far from the fertility of the soil: In most countries, 80 to 90 percent of the population depended on farming for at least part of their livelihood. Few lived in towns, and few towns sheltered more than 20,000 inhabitants. In hard times, even the capitals shrunk: Paris had wolves roaming through it in the early 1600s. Even in the relatively small and healthy towns of the American colonies, death rates were high (although declining in the 1700s). In the 1750s, 50 of 1000 Philadelphians died each year; modern death rates in the United States are about 8 per 1000 population. By the end of the eighteenth century, agricultural innovations (like crop rotation) were beginning to reduce death rates in Western Europe and the United States. Elsewhere, though, progress was slow.

Why were farmers slow to innovate? Sometimes they rejected improvements (as in plows or seeding machines) because these devices were costly or worked poorly on the hilly land that they had to cultivate. Small plots and lack of draught animals meant that hoe and spade cultivation was sometimes the only viable method of farming.

A central roadblock to agricultural innovation was transportation. Land travel was slow and expensive, reducing any incentive to specialize or innovate in hopes of reaching an extended market. The problem was not only by dependence on foot and hoof, but roadmaking technology had scarcely improved since Roman times (see Chapter 2). Roads from villages to market towns were scarcely more than cow paths in much of Europe and colonial America. Rivers and coastal waters were often the only practical method of movement of many products, especially heavy ones. Lighter or highly valuable products like sugar, salt, and tobacco could be shipped almost anywhere despite the cost; so could luxury goods. But it is no accident that markets for these products were usually linked by the sea, across which goods could be transported far more cheaply than over land. Beginning in the late seventeenth century, Western Europeans began digging canals that linked towns and river systems to facilitate the movement of grain and other goods between towns and river systems and to encourage specialization. Still, in most places the high costs of transportation assured relatively narrow and localized markets. This guaranteed self-sufficiency and with it inefficiency.

Finally, uncertain harvests also helped to perpetuate a complex web of conservative practices that seem so baffling and so self-defeating to the modern reader. Peasants generally diversified crops in hopes of spreading their risks of failure. They did so even when land may have been suited for more specialized uses. Farmers resisted change in technology or husbandry, preferring the devil they knew to the devil they did not know. All of this impeded and delayed innovation.

The New World with Old Technology

While colonial farmers brought much from their European homelands, their experience farming American soil changed their lives greatly. The first years of settlement (at Jamestown in 1607 and Plymouth in 1620) were hard.

Though they did not experience famine beyond the first years, colonists remained backward technologically and only slowly adjusted to new conditions. In fact, the Pilgrims lacked plows for twelve years after their arrival in New England. English axes continued to be used for a century, despite their inefficient straight handles and their cumbersome, unbalanced heavy heads that often broke in cold weather. It took more than a century for the colonists to adopt a smaller, lighter, balanced axe with the familiar curved handle.

The first colonists came with traditional expectations and skills that were often ill-adapted to the new environment. Early settlers in New England lacked knowledge of firearms and hunting (a skill reserved to the nobility in Europe). They also often continued to use construction methods unsuited for American resources. These settlers roofed their houses with straw thatch just as they had done in southern England even though without the English rain, they were often a fire hazard. Gold-hunting colonizers of Jamestown in what became Virginia lacked the skill or desire to be productive farmers or to cope with new semitropical diseases. All of this contributed to the 'starving times' in the 1610s.

Colonists lagged far behind the English in the construction, size, and complexity of their housing. Seventeenth-century houses in Virginia and Maryland were single story, with one or two rooms that often had to shelter large families. As late as 1798, 67 percent of dwellings in central Pennsylvania were less than 400 square feet (compared with new American homes today, which average almost 2,700 square feet). Even in civilized Boston, two-story homes with foundations and brick fireplaces with chimneys were unusual even among the more affluent until after 1750. Though stone and brick construction became common after 1690 in England, it was slow to develop in the United States.

Eventually, settlers learned from their surroundings, especially from the native peoples they encountered. Shortly after the founding of Jamestown in 1607, John Smith found numerous fields that had already been cleared for corn and other crops by the indigenous peoples. New England settlers learned how to make cornmeal and hominy from the natives. The Indians taught them the art of mounting soil around the seedlings for support, and of using corn stalks as poles for beans planted in the corn fields. Colonists adopted also the Indian custom of burning forests and underbrush to clear the land for farming (although they primarily cleared land by cutting down forests). The critical technology of growing tobacco was borrowed from the Spanish (who learned it from the indigenous people of the West Indies). German immigrants to Pennsylvania improved on English agricultural techniques with deep plowing, crop rotation, and manure fertilizing.

Most importantly, colonists took advantage of a bountiful land and, in the process, broke from the ecological balance that the indigenous tribes had long preserved. Settlers in both New England and Virginia were astonished by the variety of game and vegetation available. While Puritans in Massachusetts encountered wild strawberries and flocks of up to five-hundred wild turkeys, Virginian colonists found large numbers of deer and fish. After some time of adjustment, a colonial frontier family could provide for its food needs of corn, pork, and chicken with little more than a month of labor—freeing the rest of the year for clearing land, food preservation, and even part-time manufacturing.

From the perspective of the settlers, the Indians did not take advantage of the land. Native peoples mixed farming (done mostly by women) and hunting (male). They seldom attempted to store surplus food, much less accumulate wealth. This obliged the Indians to move frequently to find fresh fields and more plentiful game and it meant low population. European settlers adopted a very different attitude toward the land. They settled permanently, assumed ownership of the land, and thoroughly exploited it. Colonists denied Indians the right to the land because they did not 'improve' it. The native people gradually adopted many of the attitudes of the European settlers, including the mass hunting of beaver and other animals for sale on the fur market (which decimated their number).

In the colonies, hunting became a necessity (to rid fields of pests and as a source of food), setting the stage for the modern American love of hunting and firearms. A group of hunters from Kentucky returned one day in 1797 bragging that they had bagged 7941 squirrels. In the popular ring hunt, armed men encircled a large area, gradually closing in on all the game they could entrap. Eventually, this led to the disappearance of wildlife (for example, the slaughter of the millions of carrier pigeons that ultimately led to their extinction). Similarly, some cash crops adopted by settlers were extraordinarily wasteful of soil nutrients. Tobacco grown in the South drained nitrogen and potassium from the soil, forcing early planters to move to fresh land after only three or four years.

While the settlers destroyed the ecological balance that prevailed before their arrival, they also created a new environment that made them healthier and richer than they had been in England. American colonists gained over their European counterparts not by their superior technology or exceptional hard work, but by the New World's advantages in natural resources and low population. At first, this superiority was not apparent. Life expectancy in Virginia and other southern colonies in the first half of the 1600s was often lower than in England (due to typhoid, malaria, and dysentery especially). One of the main rationales for slavery was the adaptability of Africans (as compared with whites) to tropical diseases in the semitropical conditions of the Carolinas, where they were put to work in rice fields.

Gradually, the advantages of a bountiful land became apparent; and by 1650, in New England, a male reaching the age of 20 had a life expectancy of 45 more years. By 1700, superior natural resources made possible a very rapid growth in the colonial population, both north and south, which roughly doubled every 25 years. Most of this growth came from extraordinarily high birth rates and early marriage: In the eighteenth century, from 40 to

60 births per 1000 population, compared to a range of 35 to 40 in England. Colonial women became wives between the age of 20 and 23 compared to about 26 in England. Although the death rates of slaves were higher than those of whites, they were much lower than for slaves in other parts of the New World. By 1720, the slave population in the English colonies began to grow due to birth rates that eventually were as high as those of whites.

The new land posed both challenges and advantages that quickly shaped basic techniques. While English colonists were accustomed to sheep husbandry, New England lacked the meadows of old England essential for grazing. In any case, shepherding was a time-consuming task that required expensive specialists that were not available. Colonists learned to change. The pig was an obvious food substitute for it adapted to foraging in the open forest. American farmers adapted to the land in many other ways. The plentitude of the land soon led colonists to abandon their English-style farming villages for dispersed isolated farmsteads. Colonial farmers adopted a unique layout of cheaply constructed buildings, to which additional structures like barns and chicken houses were attached.

Settlers from deforested regions of southern England found vast forests in the New World. The most demanding of the new conditions was the need to clear land of trees for farming. This required the laborious task of chopping down trees and removing stumps. A typical farmer could hardly have cleared more than four or five acres per year. The upside of this was that lumber became a valued product in the 'Wooden Age' of the colonial era. Farmers often earned more income from timber than from grain or livestock. They sometimes sold lumber to charcoal-fired iron furnaces. These operations often preceded farmers in the westward trek; the demand of iron furnaces for this essential energy source paved the way for profitable farming even if its consequence was often thoughtless deforestation. Charcoal from wood was also essential in gunpowder, printer's ink, paint, medicines, and even highway surfaces and toothpaste!

American lumber was exported for ship masts, barrel staves, and construction. Many farmers boiled wood ash, collected after trees were burned, for potash and lye. These by-products were essential for making glass, soap, and gunpowder. In the 1700s, about half the cost of land could often be regained by the sale of potash from cleared lumber. Pine gum was made into rosin (for paints and turpentine). Boiled tree tar was essential for caulking hull seams. These wood by-products were definitely 'low tech.' Pine gum for rosin (used in glue, varnish, and ink) was gathered by cutting a gash in the pine's new outer layer of sapwood, from which pitch flowed. Tar was derived from pine logs slowly burned in crude piles covered with dirt. Tar was essential in shipbuilding. These were wasteful uses of Carolina pine, but they were cheap ways for farmers to dispose of trees.

Wood fences became important in the New World to prevent pigs and cattle from escaping into the wild or destroying crops. Fences had to be 'hog tight and horse high.' The building of fences was a time-consuming and expensive task, often costing as much as the land they enclosed. Americans also gradually changed their house-building techniques. Again, colonists adapted to their special conditions. In the North, settlers eventually substituted wood shingles for thatch; they took advantage of cheap wood by building larger fireplaces, which often doubled for heating and cooking functions; and they added cellars for keeping roots or vegetables. By 1700, the log cabin had become a common sight; it took much less time to build than the more stately English brick buildings, and was more heat efficient than the common English clapboard house. Because timber was cheap, whereas carpenters were expensive, many farm families built their own homes. Introduced by the Swedes into the Delaware River area in 1638, the log cabin was copied by Scotch-Irish settlers in the middle colonies by 1700. This structure required about 80 logs, which were fitted with notches (no hardware) to form the walls. Gaps between the logs were filled with clay or moss. A ceiling of poles or boards provided the floor of a sleeping loft that was reached by a notched log ladder. Windows were without glass, covered instead with greased paper or shutters. Nearly any farmer could build a log cabin from trees that had to be cleared from land anyway. As innovative as the log cabin may have been, it still symbolized the backwardness of colonial life to Europeans. Yet it also reflected the need of settlers to devote scarce time and money to activities other than domestic comfort (Figure 1.5).

At the time of the Revolution, nearly 90 percent of the colonists still earned at least part of their livelihood by farming, lumbering, and hunting. Trade was largely confined to naval stores, timber for shipbuilding, and tobacco. To be sure, success in growing foodstuffs and iron production made Pennsylvania prosperous, but these products were mostly consumed locally. They could not be competitively exported.

Colonial American agriculture suggests a complex picture: Settlers had few technological advantages over their English counterparts, and they had to encounter many extra difficulties in clearing land, building roads, and adapting to new natural resources and climatic conditions. The life of most colonial Americans was harsh. Yet, given the plentitude of fertile soil, many whites owned land or had prospects for doing so. All of this shaped the attitudes of Americans toward technology. They valued work methods and tools that reduced labor time even if they wasted apparently limitless resources. Americans had no corner on innovation and, in fact, lacked a major impetus for technological change—a specialized economy. But they learned quickly to adapt to new conditions. And many Americans came to link technological change with prosperity rather than see it as a threat to the status quo. The full impact of these attitudes, however, would take generations to realize; and they were counteracted by other factors that slowed the pace of American innovation. This will become clearer in the next chapter on preindustrial crafts.

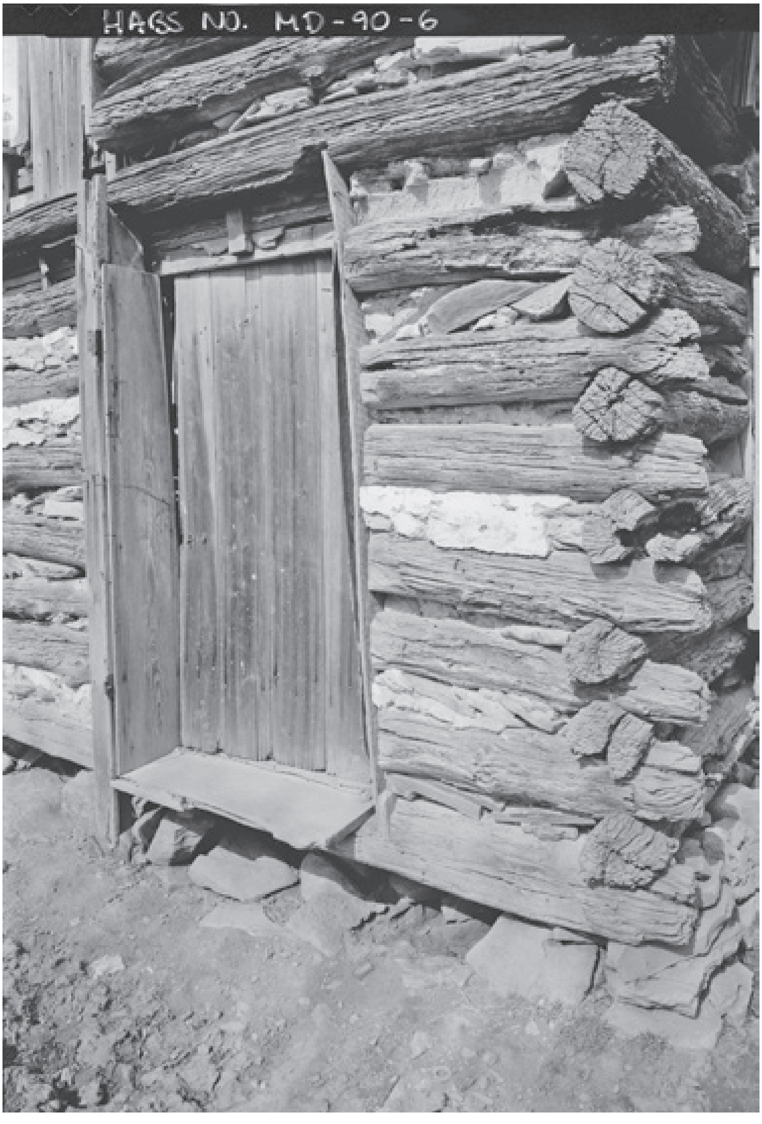

Figure 1.5 An early nineteenth-century log house showing notching and fill between the logs.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Note

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2 Men and Women Working in Shops and Homes before Industrialization

If asked to think about the preindustrial artisan, many of us would recall storybook images of butchers, bakers, and candlestick makers. And we might not think of the skilled work of female spinners of yarn. A better feel for the world of preindustrial tools is to spend a day at the Smithsonian's National Museum of American History, Colonial Williamsburg, Old World Wisconsin, or one of the many fine state and city historical museums. That traditional way of life was more competitive and dynamic than we often presume, and craft work was more complex and arduous than we often imagine. While Americans inherited craft traditions from Europe, they also adapted their technologies to New World conditions. And though the social world of the artisan was static in comparison to contemporary factory work, it was from craftsmen that modern industry emerged. Moreover, though craft work was usually separated by sex, both men and women engaged in tasks that were often skilled if also often laborious. We will explore both, beginning with mostly male crafts.

Male Crafts in a Frontier Society

Men's craft work in the seventeenth and eighteenth centuries can be most simply characterized by the simplicity of its tools—and this meant that labor often was both skilled and exhausting. The shape and function of ordinary hand tools did not change much over the centuries. Blacksmiths' hammers, tongs, and anvils were relatively static after about 500 CE. Even the stone-age axe, with its smooth wedge with swollen sides that both cut and cleaved is very much like the colonial American axe. Artisans often constructed their own tools. Carpenters made their own gauges and even planes until the 1850s. While blacksmiths purchased anvils, they often made their own tongs and files.

There were some power tools: The basic art of 'turning' wood dates from the sixth century BCE: Wood, fixed in a rotating spindle, was shaped into a cylindrical piece (e.g., table leg) with a handheld chisel. The ancient lathe, turned by pulling a cord wrapped around the spindle, was refined in the Middle Ages with the pole lathe. This device was powered by the spring of a pole suspended overhead and operated by a foot pedal and cord. Other lathes were powered by treadles, hand-cranks, or even horse treadmills.

More significant were the experienced eye and hand required to determine the proper heat of the iron to be shaped and the depth of the planing of the wood for the making of furniture. Patterns or models were rarely available to make copies of parts that needed to be fit together. We still wonder at how violins and other complex musical instruments were made by hand, and at how they still sound better than those made with modern industrial methods. The artisan's work was also often backbreaking and repetitive. The seemingly endless pounding of iron on anvil or pressing of inked type to paper must have made a long day seem even longer, even if master craftsmen often relegated repetitive and heavy tasks to apprentices.

Let us now take a brief tour of the male crafts that were common in the two centuries after 1600. In nearly every village was a blacksmith. Out of iron, he made the essential tools of farm, shop, and home: He fashioned plowshares, iron ' tires' for wagons, fireplace utensils, and the ever-essential horseshoe. Blacksmiths worked around the charcoal fire of the hearth; there, iron was heated to a glowing red heat with the aid of air from bellows. At the anvil, the smith selected from his array of hammers, chisels, and cutters to shape the iron. No small skill was required to know when to remove the iron from the fire, how to fashion chains from bars of iron, and when and how to harden metal or to anneal (soften) it. Frontier blacksmiths seldom specialized as they did in England; instead, they did everything from repairing guns to fashioning simple candlesticks.

The technology of blacksmithing formed the basis of the relatively sophisticated craft of gunsmithing. The lock that comprised the firing mechanism required many parts that had to be drilled, filed, and tapped for screws to be fitted together. Barrels were made from a long 'skelp': a thick sheet of iron heated in a charcoal-fired forge and folded around a specialized anvil called a mandrel. Then the barrel had to be reamed for a smooth and true bore, through which the ball or bullet passed. Probably the greatest skill, however, was required in the making of the gun stock or wooden portion of the gun: A man working with chisels, planes, and gouges fashioned the stock to fit a specific lock and barrel, one gun at a time (Figure 2.1).

Almost as important as the smith was the village tanner. Leather was not only a basic material of clothing and shoes, but it was essential for harnesses and even moving belts on machines. First, tanners crushed and seasoned tree bark in large vats into which animal skins were soaked to make leather. Like so many crafts, 'cordwaining' or shoemaking relied on a small number of tools: A leather stirrup tucked under the cordwainer's own heel held the work in place, while the shoemaker used awls to puncture the leather, and scrapers and knives to cut and shape the leather to be sewn together. Soles were tacked to wooden 'lasts' of different sizes, which kept the shape of the uppers as they were sewn onto the soles. An apprenticeship of 5 to 7 years was required to master this

Figure 2.1 A blacksmith at work with his apprentice working the bellows of the forge.
Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

craft in England, yet many American shoemakers were less well trained. While after 1800, shoemaking was increasingly centralized in New England towns like Lynn, Massachusetts, families still worked in backyard shops called 'ten footers,' using purely handicraft methods to make shoes. Only in the 1850s did techniques change, with the introduction of sewing machines.

Forestry tools were similarly simple: The English axe was heavy, and its steel or iron edge had to be sharpened often. Felled trees were hewed or cut square into rough timbers with a broadaxe, or a smaller adze shaped like a hoe. Boards and heavier beams were cut on the ground by two men with a vertical 'pitsaw', one man sawing from a hole in the ground.

House building required skill in post-and-beam construction. Large square timbers were held together with tendons (right-angle cuts) that were placed in mortises (or square holes) in adjoining beams. Wooden pegs, rather than nails, were used to hold the heavy frame together; nails were scarce and expensive until the end of the eighteenth century. Clapboard siding and interior paneling were made like shingles by slicing sheets of rough lumber by pounding a mallet on a wide iron blade (a frow). Skilled knowledge of wood varieties was essential, as was expertise in seasoning lumber to reduce warping and shrinkage.

As colonialists gained wealth, the demand for the brickmaker grew. He used an iron mold into which he placed clay and straw for firing (heating) in a specialized kiln (furnace). The stonemason was also an essential artisan. He not only laid stone for building foundations and cellars but usually did the heavy work of quarrying and transporting it, often in simple wheel barrows. Another essential woodcraft was coopering or barrel-making. This was a skill that had scarcely changed from Roman times. Colonial coopers used oak for the staves (side sections) and hickory for the lids of barrels. These containers were capable of holding 60 gallons or more of flour, beer, and almost everything that was shipped in quantity. Cabinetmakers were the aristocrats of woodworkers. Their skills extended from joining boards and wood turning to knowledge of veneering, varnishing, and wood grains. Cabinet makers, especially in towns, had also to keep abreast of style changes in order to compete with imported furniture.

The universal need for containers and window glass made the glassblower a valued artisan. Once again, this was an ancient craft, dating from the first century CE. In a furnace charged with charcoal, the glassblower cooked a mixture of sand, potash, and often lime into molten glass. He then drew the glass gob onto a long pipe, into which he forcefully blew air, creating a cavity for a jar or bottle. This job required both stamina and a gentle touch. Only in 1825, with the development of mechanical glass pressing, was the glassblower to begin his long decline (Figure 2.2).

Water Power and the Iron Furnace

For most of the crafts just described, muscle power did most of the work. But the colonists also inherited medieval European water power technology.

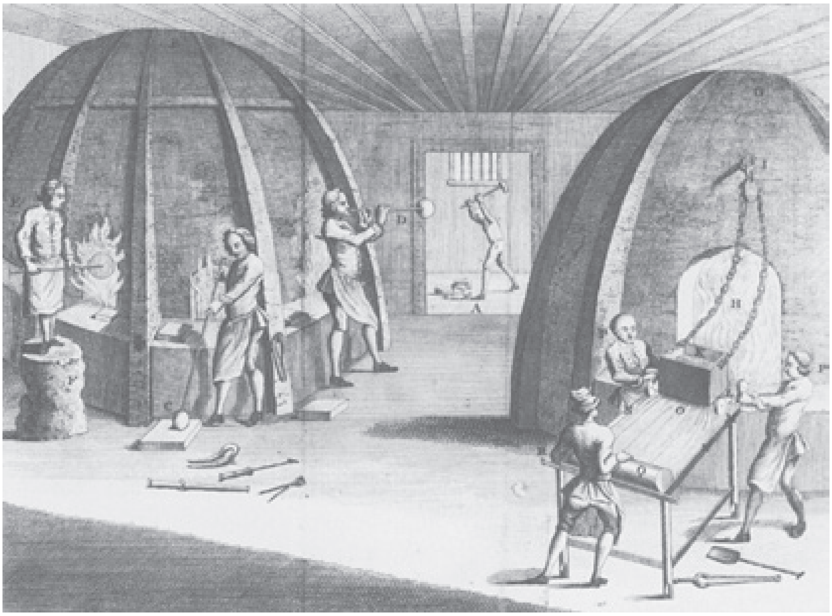

Figure 2.2 Men blowing glass into jars and making plate glass in mid-eighteenth century England.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Thirteenth-century Europeans recovered the vertical waterwheel (first invented by the Romans but seldom used). This mechanism was simple but powerful: The shaft of a wheel, turned with moving water, intersected with a gear that shifted the plane of rotation from the vertical water-wheel to a horizontal mill stone that could grind wheat into flour. Also, cranks attached to the wheel made possible the reciprocating motion of a vertical saw to cut lumber. Also connected to the water-wheel were cams (wheels with a flat portion). The shafts of heavy hammers rose and dropped as the cams turned (valuable especially in iron forges) and wooden blocks pounded cloth to flatten and tighten the weave (fulling).The waterwheel powered bellows that injected air into blast furnaces that smelted metals and ran pumps that drained mines.

The builders of waterwheels were called millwrights. They decided where to dam up a stream with stone, wood, and dirt to direct and increase the water flow that pushed the waterwheel. Millwrights constructed wooden races or channels (sometimes up to a mile long) through which the water flowed on its way to the waterwheel (Figure 2.3).

The waterwheel was an essential link between the artisan and the industrial age. Beginning in the 1790s, the American waterwheel began to power new spinning machines that were at the heart of the first industrialization (see Chapter 4). Modern industrial automation also began with the waterwheel. In the 1790s, it powered Oliver Evans's automated gristmill in Delaware that moved grain through a series of conveyors to the millstone that ground it into flour.

Waterwheels were obviously cheap to run; they could cut work time by 90 percent for such arduous tasks as milling flour and sawing lumber. By the 1820s, there was one water-driven lumber mill for every 142 New Yorkers offering them clapboard homes instead of log cabins.

Despite the mills' ubiquitous presence, they had grave limitations. They required flowing water, often requiring a location in the country, sometimes far from markets. And, in cold climates, watermills could not function in winter; droughts also shut them down. The wooden moving parts of the watermill also had to be replaced after a few years. Perhaps we should not be surprised that the coal-burning steam engine would eventually replace the waterwheel—although, especially in the United States, this took a very long time.

The waterwheel was, like so much else in colonial America, a wood-based technology. But metals were also essential. Mining was closely related to the agricultural and timber industries. In early colonial days, part-time farmers dug iron ore with a spade and pick from bogs and outcroppings close to the surface. Iron in relatively small quantities was used mostly for farm implements, nails, cutting tools, horseshoes, and machine parts where wood simply was unsatisfactory. Demand for iron goods was so small that iron smelting and forging long remained a local rural handicraft. The exception, of course, was in weapons. But even the military demand for metal was intermittent because weapon technology changed slowly (see Chapter 11). Thus, there was little incentive to build large iron smelting or forging works.

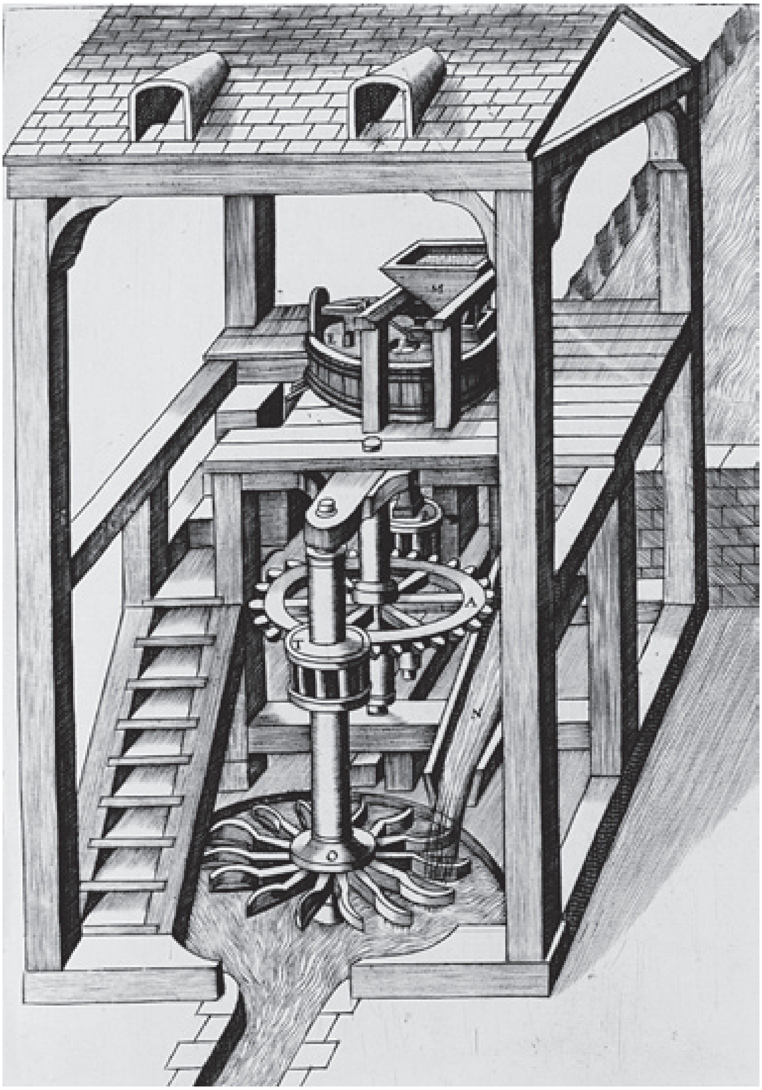

Figure 2.3 A cutaway of a waterwheel-powered saw using the 'undershot' method. Other waterwheels had water pour over the wheel ('overshot' method).

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

The refining of wrought iron was mostly done in small rural furnaces near ore and charcoal supplies. The high costs of transporting ore by wagon and the fact that charcoal pulverized if shipped prevented more centralized production. Charcoal for fuel was probably the key to iron refining: From 25 to 40 cords of logs had to be carefully packed into a mound covered with wet leaves and ferns, with a central opening at the top. The mound was slowly burned in a process lasting several days. This required great skill in maintaining just the right temperature to assure a uniform reduction to charcoal.

The most archaic method of making iron was blooming. This was a time-consuming process of repeatedly heating and beating a pasty ball (or bloom) of iron ore. Gradually impurities (especially carbon) were driven out, producing a malleable form of wrought iron used primarily in making farm tools and horseshoes. Greater quantities of iron were produced in blast furnaces. Developed first in the sixteenth century in Germany, they were a familiar sight in Colonial America. These stone furnaces, shaped like flattened pyramids, were often 15 to 30 feet high. Into the top of the furnace were poured iron ore, charcoal fuel, and limestone (as a flux to carry away impurities in the ore). The furnace shaft widened gradually to form a bowl that held the molten mixture; this, in turn, led to a narrow passage called the crucible that received the melted iron and liquid impurities, or slag. Into a small hole at the bottom of the crucible was fitted a bellows powered by a waterwheel, which superheated the contents with blasts of air. The relatively light slag rose to the top and was drawn off through a hole high in the crucible. The molten metal gathered at the bottom of the furnace. Occasionally it was tapped and flowed into sand molds. The configuration of these metal globs reminded the premodern mind of piglets suckling at their mother's breast, and hence the iron was referred to as 'pigs' or pig iron.

This process, of course, was much faster than blooming (producing 7 tons or more in a week). But blast furnace iron was a hard and brittle variety with a high carbon content (up to 4 percent) from the charcoal fuel. This cast or pig iron was good for pots, kettles, and firebacks, cast from molds. But iron for tools required tenacity and toughness that cast iron lacked. This required further refining (similar to blooming) to eliminate most of the carbon and to restructure the iron for toughness. In 1700, only about 1500 tons of the world's output of 100,000 tons of iron were produced in the American colonies. By 1775, that figure rose to 30,000 of the 210,000 tons of world production.

Steel was both rare and expensive. A variation of wrought iron with a tiny but essential percentage of carbon, steel was vital for making sharp edges on cutting tools. Colonists had to be content with small strips of steel made from wrought iron, plated onto iron surfaces. These slivers of iron were placed in closed clay vessels containing charcoal dust and heated until fused. This process was very expensive, requiring 11 days of high heat.

Despite the advantages of the charcoal-fired blast furnace over blooming, these furnaces placed serious limits on the growth of industries requiring ferrous metals. They depended upon expensive charcoal and were tied to rural points of production. Still, Americans stuck to this technology long after the English adopted coal-based coke furnaces. The cheap American wood supply may explain this. American iron output lagged long behind Britain (see Chapter 5). Some argue that this reliance on wood for fuel and machine parts actually slowed down American industrialization.

Transporting Goods and People

A far greater impediment to economic growth, however, was the high cost of transportation in colonial America. This was an age-old problem that goes far in explaining why crafts remained so unspecialized in the New World for so long: The cost of slow and cumbersome overland travel could quickly exceed the cost of production. Thus, there was no incentive either to expand output beyond the immediate market or to seek to gain cost and price advantages in a wider market by specializing—or adopting new technology.

Overland transportation was especially difficult and expensive. At first, colonists followed the paths of native peoples and migrating animals. However, these trails were too narrow for wagons because they were often located on hill ridges (where sparser tree growth eased travel).

Pack horses and mules were the principle means of overland travel until the eighteenth century on the East coast, and for much longer on the westward frontier. Even roads in low flatlands were often merely lanes cut from the forest, just wide enough for two wagons to pass.

So poor were American roads in the eighteenth century that even tree stumps were not always removed. In fact, an 1804 Ohio law required that these stumps be no more than 1 foot high! Low spots, bogs, and shallow streams were forded with the aid of rows of logs (corduroy roads). Bridges of wood were sometimes covered to reduce deterioration, but they compared unfavorably with English stone bridges. In the mid-eighteenth century, horse-drawn coaches traveling from New York to Boston took six 18-hour days.

Only in the 1790s were privately owned turnpikes built. The best were constructed with stone foundations and gravel. The Lancaster Turnpike from Philadelphia to Lancaster, Pennsylvania stimulated a raft of similar roads that promised both profit and progress. Only in 1808 did the federal government agree to finance the Cumberland (later National) Road (first between the Potomac and Ohio rivers)—but it was 1850 before the road reached St. Louis. Much of the problem was political: This project was hampered by interstate rivalries and resistance to government financing. But the large-scale earthmoving required for a national road system was truly formidable: Builders depended on ox-pulled wooden road scrapers and hand barrows (used to dig as well as haul).

Great distances between settlements required cost-cutting measures: Sometimes Americans used sea shells, charcoal, and even corncobs as substitutes for expensive road rock. But Americans also adapted the English innovation, the macadam road. It consisted of layers of crushed rock topped with gravel and fine limestone that was built up at the center of the road. This made for a hard, smooth surface that drained water. Americans also adapted their wood surplus to road construction in the 1840s: They built 'plank roads' consisting of pole stringers upon which were laid thick wooden planks. Plank roads were cheaper to build than stone-and-gravel turnpikes. But they had to be replaced every five years, and thus proved unprofitable and disappeared after 1857.

The most common vehicle on these roads was the Conestoga wagon. This American adaptation of the English farm wagon appeared first about 1716, near Lancaster Pennsylvania. The Conestoga wagon is famous for its long and deep beds that dipped in the middle to discourage tipping when heavy loads shifted on hills or uneven roads. Its six-inch-wide wheels allowed the Conestoga wagon to get through the ruts so common on dirt roads. This vehicle was an excellent adaptation to poor American roads. Its descendent, the 'prairie schooner,' did the same job in the wagon trains that snaked along the Oregon Trail in the 1840s and 1850s.

In colonial times, it cost more for Atlantic seaboard towns to ship coal ten leagues (about 30 miles) by land than a thousand by sea. But travel by water on rivers was no easy task. Colonists copied the birch-bark canoe of native Americans for travel on shallow waterways. The lack of seaward flowing rivers in New England limited the growth of Boston. By contrast, New York City had access to water highways northward from the Hudson to the Albany and the Mohawk Rivers, and onward to Lakes George and Champlain. The long reaches of the Delaware and Chesapeake Bays connected the coasts of the middle colonies with the interior via the Delaware and Susquehanna Rivers. Further south, the Potomac, James, and Savannah rivers all eased the flow of goods into the plantation economy. But traffic between colonies necessarily depended on coastal boats, a fact that slowed the pace of western expansion (Figure 2.4).

Even before the steamboat, the Ohio and Mississippi river systems made possible the shipment of bulky goods too expensive to haul over land.

Figure 2.4 A Conestoga Wagon like those used at the beginning of the nineteenth century.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Flatboats combined shallow-draft construction with relatively large capacity. Still, the downstream journey from Pittsburgh to New Orleans could take two months or more. The upstream trip, of course, took longer (up to six months) and was more arduous. In places, men had to push long poles into the river bed or animals had to tow boats from shore paths. Although improved roads and a good river system encouraged growth, only steam-powered boats and locomotives made possible a continental economy and a shift from crafts to the modern factory (Figure 2.5).

The Culture of the Crafts

An assessment of the artisan age should go beyond its tools and work methods. We need also to consider the life and culture of the artisan and how that shaped attitudes about technological change. The mostly male artisan's workday was

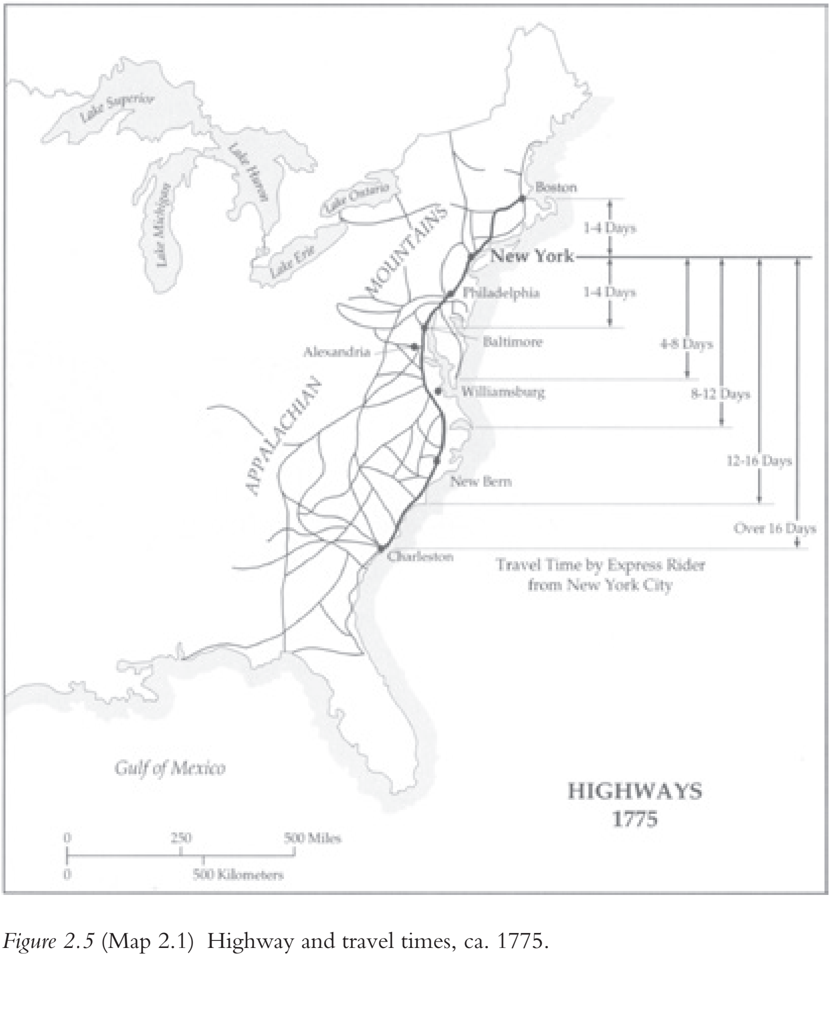

Figure 2.5 (Map 2.1) Highway and travel times, ca. 1775.

long, often extending from sunup to sundown. Low productivity made shorter days impossible. But tasks rather than fixed hours determined how long a person worked: Because most jobs began when customers placed orders, an artisan's day could extend into the night during seasonal rushes, but days or even weeks could be free for farming or hunting when business was slack. Especially skilled artisans could afford to work less, spending part of the month in a 'side' business. American craftspeople found ways of breaking the routine of work. No assembly line or profit-driven boss impeded the occasional break from work to watch a street boxing match or share a drink with a friend. Early in the nineteenth century, New York shipyard workers took candy and cake breaks at 8:30 and 10:30 am. Groceries as well as bars sold 'strong drink' in craft districts, where artisans often drank a full quart of gin on the job each day. Artisans were proud of their skills and were reluctant to see themselves merely as laborers selling their time; rather, they considered themselves to be 'independent contractors', even within an employer's shop.

Still, it is easy to romanticize this preindustrial work culture and its freedoms. Bad weather and uncertain markets meant that many artisans had to supplement their craft income with other work like farming and even hunting in rural areas in order to survive. And, especially in cities, many an artisan eked out a very poor living in an annual cycle of wage-less leisure and debt-driven overwork.

Artisans differed widely in their income and social standing. Urban master craftsmen like Paul Revere, a silversmith, were often leading figures in church and community life. Artisans in the urban building trades could start as poorly paid journeyman carpenters and end their careers as wealthy contractors employing dozens in the construction of homes and businesses. However, many artisans were scarcely better off than the working poor. Those trades that required lesser skill or few tools, or where women predominated, were especially low paying. Common tailors were at the bottom of the economic and social hierarchy; they needed little more than a needle and thread to practice their trade. Other low-status crafts were shoemaking and candlemaking. Ben Franklin rejected his father's lowly occupation of soapmaker for the more profitable and prestigious craft of printer. Male artisans in these trades often depended on the labor of family members to eke out a meager living. And many in the garment trades worked at home and depended on materials provided by merchants who took advantage of them by offering low piece rates (a system called 'sweating').

Even higher status artisans were not the equal of merchants or lawyers. Silversmiths, furniture makers, and tailors relied upon the patronage of fussy wealthy people, who insisted on imitations of the latest European styles. Even portrait painters were seen by these gentlemen as mere manual laborers. Indeed, the distinction between artist and artisan was blurred. Charles Willson Peale, the famous 'limner' or portrait painter of George Washington, was at various times a saddlemaker, upholsterer, and silversmith. Artisans had a particularly hard time in the South, where the plantation economy predominated, and many finished goods were imported. White craft workers sometimes had to compete with skilled slaves (even though few blacks were allowed to learn high-status trades like printing).

Conditions for the development of artisanship were better in the North. There, family farming and overseas trade produced a demand for handicrafts, a difference that goes a long way toward explaining the early industrialization of the North. Even so, compared to the English, colonists in the North lacked skill and specialization. In part, as we have seen, Americans became 'jacks of all trades' because of widely dispersed rural communities and labor scarcity. Apprentices often managed to escape from their obligations (as did the 17-year-old Ben Franklin who ran away from his brother's shop in Boston in pursuit of plentiful work in Philadelphia). Sometimes artisan fathers found themselves in competition with their young adult sons. Labor shortages (and plentiful land) gave young artisans opportunities that prevented the long training required of skilled specialists.

But this same seemingly precarious and backward situation of craft workers also tended to produce uniquely individualistic attitudes toward work and business. This is probably the origin of the often-observed adaptability of the early American artisan. Oliver Evans, although trained as a wagon maker, moved easily into the profession of millwright, and from this into a career of inventing labor-saving machinery. His varied experience allowed him to synthesize diverse elements of existing technology into new inventions. In this, he was hardly different from others, such as Eli Whitney, John Fitch, and Cyrus McCormick. Improvisation and practicality, more than care for detail and quality construction, were valued. American artisanship produced inventors who were obsessively seeking ways of reducing labor and saving time in a country that was in a hurry to build wealth. This would produce much waste (as we will note in later chapters). But it also created a vital technological flexibility.

Many American artisans shared with Franklin a deep-seated work ethic: "He that is prodigal of his time, is in effect a Squanderer of Money … *Time is Money*."[1] Hard work in youth was to pay off in economic and social independence in middle age (as it did for Franklin). And, even if that goal became increasingly unattainable in the nineteenth century the dream remained for many. The artisan with his roots in the preindustrial world played an important role in creating the coming age of mechanized industry—even though some resisted this change and were displaced.

Colonial Women's Work and the Real 'Traditional Housewife'

If asked to imagine women's work before industrialization, most of us would picture maids at the spinning wheel and mothers tending to hordes of children, far removed from male crafts and farming. As with our impressions of male artisans, our thinking about preindustrial women's work is distorted by later industrial experience and colored by storybook memories. A more complex and more interesting picture emerges from the experience of colonial women's work in the home.

Central to preindustrial society and woman's role in it was the concept of the household or 'domestic' economy. This meant that work was organized among members of a family and their servants and that most work was conducted within or near the home. First, this meant that women's work was generally homebound because women were obliged to combine both family duties (child care) with goods-producing work to maintain her family and often to earn money. This usually meant little time to make the home a center of family togetherness and comfort that many people associate with the roles of the 'traditional homemaker.' The real traditional housewife was fully integrated into the family enterprise, be it farming or blacksmithing. Second, the domestic economy allowed no sharp separation of space or time between work, family, and leisure. Spinning and cooking along with socializing and child-tending often took place in the same room at the same time. Few commuted to work. Third, the sexual division of labor was not as pronounced as it would be later with industrialization. Women sometimes joined men harvesting grain or tending (and even slaughtering) pigs. Colonists saw some of this as temporary, due to scarce labor. Still, women's work was often closely related to men's work. Artisans like the printer Benjamin Franklin relied upon their wives to attend the shop (or even keep accounts) while they traveled or worked at the press or forge. So important was women's work and their responsibility to care for children that wives sometimes took over husbands' farms and trades when widowed or when the men were away at war or on business. Colonial women did the family work that today we associate with private life like cooking, childrearing, and housecleaning. But they also took on jobs that brought income like producing butter for sale or tending a bar at home selling beer she brewed. Her life was less isolated and private than it would become when these tasks were relocated to factories and separate businesses (Figure 2.6).

Varieties of Women's Work and Their Tools

Let's take a brief tour of women's work in the colonial era. Female labor was mostly devoted to primary rather than finishing or 'secondary' domestic functions. The growing and preservation of food took priority over the culinary arts. The birth and care of babies necessarily took precedence over the training and nurturing of children. Only with industrialization, after about 1800, would this change for most women; and for wives of frontier farmers, these basic priorities would last much longer.

Figure 2.6 A representation of a colonial kitchen and cabin. Notice the size of the fireplace and the many activities.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

The center of women's work and family life was the hearth. Colonial fireplaces were often twice as large as those common in England. Plentiful supplies of wood allowed for inefficient wide chimneys. Women could stand inside these fireplaces, tending to several fires at once. The lack of matches until the 1830s made necessary the skilled use of the flint and steel in a tinder box to 'keep the home fires burning.' A lug pole stretched across the wide fireplace opening. Along this pole were strung a variety of hooks and chains to which pots, cauldrons, and pans were attached. This allowed several simultaneous fires to be kept at different sizes and temperatures for different purposes. Gridirons and long-handled skillets fried meat and meal cakes, while spits roasted larger joints of pork and beef. The fireplace also heated rooms, requiring much chopped wood provided by men mostly. But women had to clean out the fireplace, using the ash and animal fat to make soap.

A key improvement was the gradual introduction of the cast iron stove beginning in the late eighteenth century. At first scarcely more than an iron box inserted into the fireplace, it gradually became the freestanding 'pot-bellied stove.' Introduced by immigrants from northern Europe (rather than Britain), the cast-iron stove became a mainstay of America's early industrialization, widely produced for the enhanced comfort and convenience of homes. The stove provided not only a radiant heat that warmed large rooms, but wasted far less heat than did the fireplace, whose heat quickly went up the chimney. The stove was also adapted to coal that gradually replaced the wasteful use of wood. Yet women required skill to control temperature (and keeping fires alive), using vents that controlled air flows. And the stove took much elbow grease to clean.

Women also provided lighting. Candlemaking followed the autumn butchering of pigs and cattle. Women collected animal fat, which they boiled in water to make tallow. Wicks dipped into the semiliquid tallow were hung to dry into candles. Colonial women gradually adapted the legacy of European food preparation to American conditions. Mashed pumpkin and Boston baked beans were adopted from native peoples. They pounded 'Indian' corn into a powder for a breakfast mush or made into cakes and breads. From the perspective of modern tastes, colonial women grossly overcooked root vegetables (often believing that raw vegetables were fit only for pigs). Women often cooked stews of whatever meat and vegetables were available because these meals required only a single pot and little effort in regulating the temperature over the open fire. Only slowly were meat and vegetables cooked and served separately.

Leavened breads were especially difficult to bake. Many colonial and frontier families made do with pan-fried cakes. Some women used an iron box oven that was placed in the hearth to bake rolls. Only the relatively rich had brick ovens built into the fireplace for making bread. Yeast, gathered from fermenting beer or from dough saved from an earlier baking, was mixed with water and flour to make bread dough. Only after a fire had heated the oven, and the ashes were removed, could the dough be baked.

Early colonists shifted from the time-consuming task of cheesemaking, a basic source of protein in England, to pigs, which could be raised with little effort. In the late fall, women often slaughtered pigs, boiling them whole in water to ease the skinning. Females then had the 'unladylike' tasks of disemboweling the pigs (saving the intestines for sausage casings), cutting larger pieces for immediate roasting, and pickling the rest in wine and spices. Women also submerged their pork into brine to salt the meat. Many early Americans preferred salted, smoked, or pickled meat to fresh, considering this processed pork or beef 'stronger' or more nutritious than fresh meat.

This may have been making a virtue of necessity: A central problem was the preservation of food that was harvested seasonally. One common solution was for women to grow and make meals with hard vegetables like turnips, parsnips, hard peas, beans, and potatoes. These foods kept for months in a dry, cool 'root cellar.' Leafy or soft vegetables (like lettuce and tomatoes) rotted quickly and required too much attention for many farm women. Orchards provided the basic ingredient for making cider and brandy, an effective way of 'storing' fruits.

Colonial farm woman also often brewed beer. She usually bought malt (barley that had been sprouted and dried by a neighborhood expert), which she 'mashed' in water heated just below the boiling point and added herbs and hops. Finally, the cooled solution was mixed with yeast for fermentation. Women also made varieties of root or birch beers (non-alcoholic) from trees and plants around their farms.

Women and older children milked cows. Because cows could be milked only for part of the year, most milk was converted into salted butter that was edible for months. Butter churning included the exhausting task of working the up-and-down motion of the plunger to congeal cream into butter. By the end of the eighteenth century, new barrel churns with rotary cranks—or even churns turned with the aid of dogs or sheep on treadmills—eased this chore for a few lucky women.

One of the most difficult jobs that women had was washing clothes. Often washing was done on 'Blue Monday,' presumably to clean precious Sunday garments before the dirt set in the fabric. Without the benefit of indoor plumbing, it was hard work to carry gallons of water (each weighing 8.34 pounds) from a spring or outdoor pump to kettles placed over stoves or fireplaces. Often soil from the garments had to be loosened on a washboard before the clothes were boiled in the kettle while women stirred the heavy load with a wooden wash stick. Next, the wash load was rinsed (and sometimes 'blued,' or bleached and starched) before the wet clothing was lugged outside to dry. Hours were devoted to pressing, especially the easily wrinkled linen. Heavy and often specialized irons were heated over the fire or by hot ash placed inside. Garments were easily scorched or soiled with ash. The job was hot, especially in the summer.

The woman's domain, particularly on the farm, extended some distance from the house. The kitchen was the central room of the family dwelling, but it was often close to a series of outbuildings: hen and spring (dairy) houses, for example. She was responsible for a wide variety of agricultural tasks related to food preparation. These included gardening; dairying, and pork, poultry, and egg production. Often the processes and tasks were intertwined: Women gathered feathers from the chicken coops for bedding.

Often, men's and women's work were closely related and even mixed. For example, men fed and bedded cows, while women milked them. The sexual division of labor often was not based on physical strength or endurance: Men cut and hauled wood, but most women carted water from well or stream for household use. Women may have been the home-based workers and men the field producers, but few men could have survived without their wives' labor. The wife was far more an economic partner than would be the later 'traditional housewife' (Figure 2.7).

An especially important illustration of this economic role of women is their vital work in making textiles and clothing. Flax production for linen cloth was an essential occupation for women. Farm women often devoted a quarter-acre to this crop and were responsible for its midsummer harvest. Women removed the seed (used in linseed oil) and spread the flax stalks on wet ground or in ponds for rotting or 'retting'. The softened stalks were 'hackled' between combs to eliminate woody material and straighten the fibers. Women spun the shorter fibers (or 'tow') into yarn for inferior cloth or 'towels'. They made the preferred longer fiber (sometimes called 'lint') into yarn for linen clothing, coverings, and sheets.

Only in winter would the women find time to spin the flax into linen yarn. It was at this time that they also prepared wool fleece for spinning, a similarly complex process, involving cleaning the wool and combing the fleece between blocks of wood covered with bristles (carding). This produced slivers of straightened fiber or roving suitable for spinning.

Most spinning wheels consisted of a large wheel turned by a foot treadle. A cord attached to the revolving wheel turned a spindle. While the spinner stretched the roving, the spindle twisted the fiber into yarn or thread. The emerging yarn was attached to hooks fixed on a U-shaped flyer that surrounded the spindle. This simple but ingenious device wound the yarn on the spindle as it was being twisted. It was no accident that women spun yarn. It was a perfect task for mothers burdened with the constant demands of children, for it could be stopped and started at will. The same was true of knitting.

The loom for weaving yarn or thread into cloth was far rarer than the spinning wheel in the houses of colonial Americans. The loom was expensive, took up much space, and required heavy physical labor. Sometimes weavers

Figure 2.7 Colonial-era women working together.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

were professional and male. Back and forth across the frame of the loom, the weaver strung warp yarn. Each thread of warp yarn was attached to strings or wires on wooden bars. Using foot pedals, the weaver raised or lowered these devices known as 'harnesses' to create 'sheds.' The warp threads also passed through the narrow slots of a metal or cane reed, which separated them. After each pass of the shuttle, the weaver used this reed (or beater) to drive weft yarn into a tight weave of the cloth. Skill in the use of harnesses and different colors of weft thread could produce distinct patterns. This was painstaking, time-consuming work. Operating the shuttle was especially exhausting (Figure 2.8).

Weaving was only one of many steps. Cloth had also to be fulled (beaten) with wooden clubs to flatten and reduce gaps in the weave. Cloth was also often dyed. And all of this work was merely a preliminary to the task of garment making in an age before paper patterns or sewing machines. It is no wonder that many women passed this task on to others when they could afford to, especially when they needed to make men's trousers or coats. Many women sewed only the simplest of dresses or preferred to mend and alter the family wardrobe instead of making new clothes.

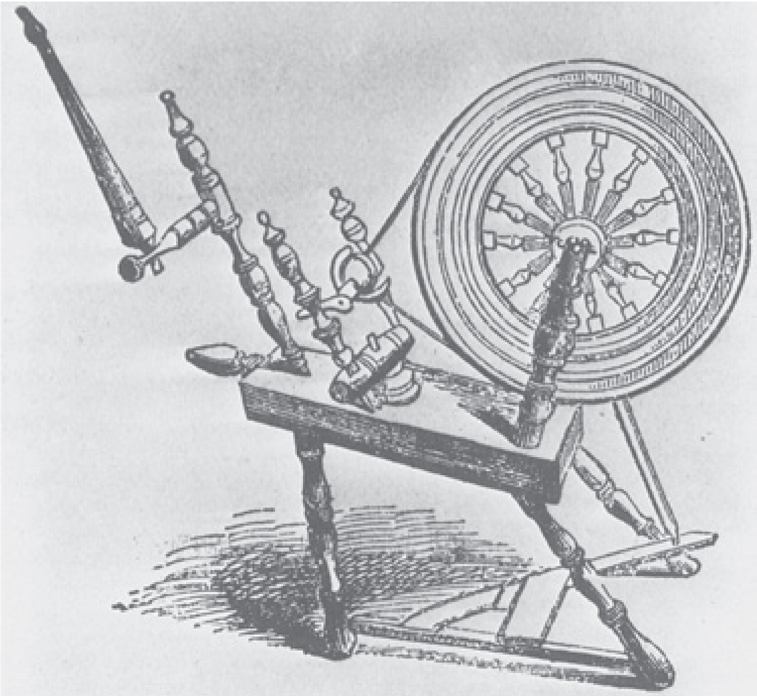

Figure 2.8 An English-style spinning wheel common in colonial America.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

While much of this work served the immediate needs of her family, the colonial woman often produced goods for at least the local market (as in brewing beer). Some women from the middle colonies/states produced butter for the West Indies. A few women, especially in towns, set up their own garment making shops, as did Betsy Ross.

Despite this picture of endless if varied toil, colonial women did find ways of escaping the isolation of domestic labor. Indeed, traditions of sharing work and trading goods were built into the system of the preindustrial economy. For example, the lack of adequate refrigeration necessitated that farm wives share fresh meat with neighbors, who in turn would repay the favor when they had a surplus side of beef. Endless and lonely work could be eased by socializing in sewing or candlemaking 'frolics.' A dozen or more women gathered in the afternoon to make a quilt over conversation. Women skilled in cheesemaking traded services with other women talented in the difficult task of weaving. Sharing work was essential, especially in the North where slaves and indentured servants were less common than in the South. But women also simply sought opportunities to escape the isolation of the farm in socializing with relatives and neighbors—though women's leisure was necessarily often combined with productive work.

Bearing and Raising Children

A dominant role in shaping women's work has been her biological function of childbearing. And this often played a greater role in women's lives in that age before today's family planning. A married colonial woman could expect a pregnancy every 20 to 30 months until menopause. There are signs that some American women sought to restrict their births. By about 1750, Quaker couples at least used abstention (and perhaps coitus interruptus or withdrawal) to avoid unwanted pregnancies. Such 'low tech' forms of birth control allowed these women to increase the time between births, and even to complete their families at a younger age than before. However, mechanical or other 'artificial' means of birth control came much later; for most, only in the twentieth century. In any case, in this preindustrial world large families were not necessarily a disadvantage. The additional members could be put to work relatively early. A large family was often security against poverty and loneliness in old age. In any case, many babies did not survive into adulthood.

Childbirth was an arena of life entirely in women's hands. Unlike the modern sterile but isolated experience of a hospital delivery under the control of a physician (usually a male), in colonial America giving birth was a communal affair involving women from the community. A neighborhood midwife, often trained by another midwife, would direct the birth, while a dozen or so female relatives and neighbors would attend and 'coach' the expectant mother. The midwife used butter or hog's grease to ease the birth. Commonly, a woman delivered her baby while being held in another woman's lap, as she squatted on the midwife's stool. Men, including the father-to-be, were not welcome. Only after the 1750s did male physicians begin to take over childbirth—a process fostered by the invention of surgical forceps in the 1770s.

Demands on the woman's time greatly limited her ability to dote on her babies. Cradles necessarily were placed in the kitchen to ease the mother's task of caring for the baby while carrying out her many other duties. Older children were frequently delegated the low-status task of minding the little ones. Childbearing confined women to the home and to tasks that could easily be interrupted by family needs. Still, the time and quality of child care was limited by the demands of the women's other tasks.

Children were regularly and at an early stage integrated into worklife. Children were strictly trained, often with harsh beatings, to assure that they unquestionably followed parental demands. Mothers taught their five- to ten-year-old daughters to spin, churn, sew, and milk cows. Teenage daughters were sometimes sent out to work in other households. The modern summer holiday from school had its roots in the needs of parents for the labor of their children.

Signs of Change by 1800

Gradually many of the goods and services that colonial women had provided their families in the home were taken over by the market and government. In the eighteenth century, more prosperous colonists purchased linen sheets and dinnerware. Women quickly adopted the use of the mechanical clock to monitor their daily routines. The introduction of such consumer goods and services signaled the beginnings of a long process: the replacement of home-made with market goods and the abandonment of home care and training for medical and educational institutions. This meant the removal of many traditionally women's jobs from the home and ultimately a shift in what women did in the home. First, as farmers grew more prosperous, and as craftsmen could afford to separate business from residence, the daily involvement of women in their husbands' economic activity diminished. Second, women gradually shifted from primary to finishing domestic work: They eventually withdrew from the brewhouses, pigpens, flax fields, and even birthing rooms, which had been essential parts of their extended domain. Increasingly they turned spinning, weaving, and sewing over to specialists and eventually factories. Instead, especially if they were middle-class, they transformed the home into a center of comfort, recreation, consumption, and family nurture. Most women probably preferred being relieved of the dirty jobs of soapmaking and pig slaughtering, and the time-consuming labor of tending the fire. But some of the special skills and activities of colonial women disappeared. In any case, with this change, came the modern idea of the 'traditional housewife' whose work lay outside the market and who was often dependent on her husband's income. This was especially true for the more affluent. Other women, especially if they were poor, took jobs outside the home in textile factories, shops, and offices, at least until they were married.

Like the male artisan, the colonial woman engaged in tasks that, however arduous and repetitive, were often skilled. But both the manual expertise of the blacksmith's shop and the manifold competencies of the farm woman in her domestic economy gradually passed from the scene. Industrialization changed it all as we shall see in the following chapters.

Note

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3 Origins of Industrialization

The complex of events that began the shift from artisan and agrarian societies to economies dominated by manufacturing and machine-made goods is traditionally called the Industrial Revolution. It began in Britain, although these revolutionary changes would cross the Atlantic to take a particular American character within a generation. Much ink has been spilled over the question of whether we should speak of an 'Industrial Revolution' of the late eighteenth and early nineteenth centuries. The word 'Industrial' is too narrow, for the changes in this period affected not just the manufacturing sector but home and farm as well. Nevertheless, one of the key characteristics of the period was that half of the British population came to work outside agriculture. Britain's industrial prowess would allow the importation of food from other countries in the late eighteenth century. Much later, in the late nineteenth century, mechanization and chemical fertilizers would emerge from the industrial sector to dramatically increase agricultural productivity. Although the agricultural sector had previously dominated the economy, from the time of the Industrial Revolution the industrial sector played that role.

Some have disdained the use of the word 'Revolution' for a transformation that took more than a century. To be sure, it was only well into the nineteenth century that economic indicators such as per-capita income started to show any dramatic change. However, even political revolutions take many years to produce their full effect. We can hardly overestimate the impact on the world of this revolution. We have described in earlier chapters the static nature of the pre-Industrial Revolution world: Although innovations occurred and incomes rose, they did so at such a pace that people expected to die in a world that looked virtually the same as the one into which they were born. Per capita incomes would more than double in succeeding generations in Britain, North America, and elsewhere.

After the Industrial Revolution, people came to expect (and occasionally fear) continued rapid technological innovation, and resulting changes in incomes, employment possibilities, skill levels, social relations, consumption possibilities, and a host of other factors. Even in the United States, where the existence of a steadily expanding frontier had always militated against a static view of reality, the Industrial Revolution quite simply revolutionized how people viewed the world around them.

The Industrial Revolution meant most of all a dramatic increase in the rate of innovation—and not just narrowly technological innovation: We discuss that all-important organizational innovation, the factory, in the next chapter. We consider also some of the major sectors in which these innovations occurred—textiles, iron, and steam engines—in the following two chapters. It is important to remember, however, that innovation happened across a range of sectors; for example, Josiah Wedgwood's transformation of the manufacture of pottery.

In this chapter, we try to understand why this revolution first occurred when and where it did. What had happened in Europe in the preceding period to pave the way? Why was it Britain that first industrialized? How did a sparsely populated United States in 1800, which gloried in its agrarian character, become by 1860 a great industrial power? And, finally, how did Americans create distinct paths to industrialization?

The Increasing Rate of Innovation from 1750

Although technological innovation is inherently difficult to measure, there can be little doubt that the rate of innovation accelerated after 1750. It was in Britain that this transformation began. Let us first consider some general trends, and then focus specifically on why Britain took the lead. A good, although imperfect, way of judging both increased research effort and successful innovation is to consider the upsurge of patents after 1750. Also, review this list of major late-eighteenth-century advances: James Watt's steam engines; the textile spinning machines of James Hargreaves, Richard Arkwright, and Samuel Crompton; the introduction of chlorine bleach and cylinder printing; Henry Cort's puddling and rolling process for making iron; and Josiah Wedgwood's revolution in pottery manufacture. Why, though, should the rate of innovation have increased so dramatically and in such diverse fields of endeavor?

One explanation is institutional. The British government had been one of the first in the world to establish a patent system in the sixteenth century (the concept was pioneered in Italy in the fifteenth century). Potentially at least, inventors, by proving that they had produced a novel device, would be granted a monopoly over the exploitation of their invention for a period of years. However, others often ignored the patent monopoly. British innovators such as James Hargreaves found their rights almost impossible to protect, despite the fact that the crown had gradually tightened up rules governing patenting. Still, the British government had in previous centuries established secure private property rights over both land and movable property. In various parts of the European Continent, the risk of arbitrary confiscation was much higher. The protection that they did have encouraged British subjects to invest and to accumulate wealth, and thus also to devote time and effort to innovation.[1]

Even without patent protection, there was still an incentive to innovate and invest because the innovator would be more familiar with their innovation than anyone seeking to copy it.

Security of property may have been especially important for religious and ethnic minorities. Britain had in previous centuries received Jewish refugees from many countries, as well as Protestant refugees from France. These people had, at the time, been important sources of technical knowledge. Although most innovators during the Industrial Revolution were Anglo-Saxon members of the Anglican Church, we do find a disproportionate role played by Protestant dissenters and Jews. For example, many critical innovations in iron-making were the work of Quaker ironmasters. Even though these groups faced no government-sanctioned threat to their well-being, they were cut off from achieving high status through the civil service or military. Such discrimination may have resulted in a group ethic that encouraged economic success. The best and brightest in these minority communities had to seek fame and fortune in the commercial world. Many naturally turned their thoughts to innovation.

Another factor that likely encouraged innovation was urbanization. Population density had expanded since the Black Death in the mid-fourteenth century. This undoubtedly increased interpersonal contact, which is of great importance because innovation is rarely the result of isolated genius. More and more, European innovation emanated from urban centers where innovators could draw upon the expertise of a range of specialized artisans. Some have argued further that population pressure is a key cause of innovation. Alternatively, one could argue that population growth lowers the incentive to adopt labor-saving technology by depressing wages. Improved nutrition paralleled increased population in the eighteenth century: New agricultural rotations and transport improvements gave the people a more varied diet. Innovators could thus devote more energy, and perhaps more brainpower, to their activities.

Others have argued that religious beliefs and intellectual changes played a role in encouraging innovation. The Reformation of the sixteenth and seventeenth centuries demystified the natural world. The faith of both Protestants and Catholics became increasingly based on inner spiritual experience, rather than being linked to traditional religious notions that mixed the supernatural and physical worlds. These characteristics of Christianity were particularly well developed in Britain, with the influence of the radical Protestantism of Puritanism as well as independent-thinking sects like the Quakers, Baptists, and Methodists. The seventeenth-century English thinker, Francis Bacon, encouraged an empirical and utilitarian tradition in England. He stressed the value of experimental insight over traditional theorizing and insisted that knowledge should be 'power'—that learning should enhance humanity's control over nature. The degree to which these cultural innovations reflected economic and demographic change, rather than the reverse, is still unclear. Many would argue that religions evolved to reflect changing socioeconomic conditions.

We do know that agricultural productivity rose during the Industrial Revolution. As we saw in Chapter 1, low levels of agricultural productivity require that almost everybody works in agriculture. Only as the agricultural sector produces a surplus can a significant industrial or service sector emerge. We should note, though, that agricultural output is often observed to rise as a response to changes elsewhere in the economy: Farmers produce more when they have a market to serve and goods they wish to buy. We do not, then, need to have an agricultural revolution immediately before we can have an industrial revolution. In Britain, it appears that growth in agricultural productivity in the eighteenth century was sluggish compared to both the seventeenth and nineteenth centuries. Thus, while Britain benefited from a relatively prosperous agricultural sector, the Industrial Revolution was not triggered by advances in agriculture.

In the three centuries before the Industrial Revolution, European industry had shifted from town to countryside—not the opposite, as one might imagine. Workers might produce goods in their homes to sell in the market. More often, entrepreneurs distributed work to large numbers of workers who labored in their own rural houses. This arrangement is often called the 'putting out system,' and the work itself the 'domestic economy.' Businesspeople were attracted to inexpensive rural labor and desired to escape the control of urban guilds. Some scholars have thought that these traditional organizations had been a significant impediment to innovation by regulating entry into trades, quality of output, size of establishment, and method of production. By moving work to the countryside where guilds were powerless, entrepreneurs were then free to experiment with new products, new tools, and increased specialization of the workforce. Recent scholarship suggests, however, that guilds served essential roles in educating apprentices and assuring quality output and may have been ineffectual in limiting technological innovation.[2]

These same centuries saw considerable regional specialization of both industrial and agricultural activity. This meant that people in particular regions would see the potential for improvement in specific lines of work much more clearly than when each region was mostly self-sufficient. Moreover, regional specialization encouraged the division of labor by allowing firms to expand in size. If each worker performed many tasks, the advantage of mechanizing one of these tasks might be slight: The machine would lay idle most of the day while the worker performed other duties. But once workers came to perform only one task, it became much easier to visualize how a machine could do the work and to see the benefit of mechanization.

The gradual nature of the changes just outlined makes them insufficient for explaining what happened after 1750. All of them likely facilitated this increase in innovation, but we are led to suspect that some more dramatic transformation in the early eighteenth century must have played a role as well. In tackling this question, we must stress that the Industrial Revolution happened first in Britain and only later spread to other countries. We should look then for eighteenth-century developments that set Britain apart.

Why Britain First?

Why did Britain experience the Industrial Revolution decades before other countries? While the American colonies in 1750 were still loosely connected and agricultural, other European countries such as France seemed to have much in common with England. But a century later European writers recognized England's technological lead and asked how it had come about. Historians have long recognized that explaining why Britain and not France (or some other European country) was the industrial pathbreaker would provide great insight into the causes of innovation.

Some have pointed to advantages in raw materials. Britain had abundant supplies of coal, iron ore, and land suited to raising sheep for wool. One cannot push this case too far, however. Britain imported half of its iron ore—primarily from Sweden—and made all of its steel from imported ore. It imported all of its cotton, and many other essential materials as well. Its far-flung empire gave it only the slightest of advantages, for its continental European competitors were able to obtain materials such as cotton at virtually the same price. Britain had imported cotton from the Middle East for decades before plantations were established in its American colonies. We have seen in succeeding centuries many examples of countries industrializing despite poor resource bases: Japan and Switzerland are the best examples. The resource argument is often turned on its head. Britain's population put pressure on its wood supply earlier than in most other European countries. This encouraged the British to explore the potential of coal as a fuel. Coal consumption per capita was much higher in Britain in 1750 than elsewhere. Coal proved to have superior technological potential, and thus Britain gained a perverse advantage from a resource shortage. Nevertheless, while coal use was beneficial in ironmaking and steam engines, it was of little importance to textile and pottery innovation. At the very best, then, we could conclude that the wood shortage was only part of the story. Moreover, although national statistics show Britain as the dominant coal consumer, some regions of Continental Europe also had coal and were experiencing a similar shortage of wood.

If resource advantage is an inadequate explanation, perhaps the British had a cultural edge. Regarding both science and education, however, Britain appears to have had no advantage over other leading European nations. Many of the most prominent scientists of the era, such as Antoine-Laurent Lavoisier and Claude-Louis Berthollet, hailed from France. In any case, the technological innovations of the period occurred far from the scientific frontier. It has been suggested that British scientists were more practically oriented than others. The French Royal Academy, however, sponsored a multivolume series of books on industrial technology, arguing that such technology could be improved only if it were first understood. Berthollet was undoubtedly concerned with the problems of bleaching when he experimented with chlorine. If British innovators were more familiar with scientific knowledge (or what was probably much more useful at the time—the scientific method of trial-and-error experimentation, with precise record-keeping), it was because they experienced a greater incentive to acquaint themselves with information available to most western Europeans.

Britain was also less prone to regulating industry than many of its neighbors. As with the guilds discussed before, government regulation could provide a significant barrier to innovation. The difference was not that Britain had fewer rules on the books, but just that it did not strictly enforce the regulations that existed. This raises a question of cause and effect: Perhaps Britain, faced with widespread innovation, was forced to abandon its attempts to enforce its regulations. In countries where changes occurred slowly, the government might find it advantageous to protect the jobs of those threatened by new machines, in order to maintain the peace. In Britain, such demands may have been too great for the civil service to manage. Although the British government in the eighteenth century might be characterized as less paternalistic than Continental governments, and therefore more willing to let its subjects bear the costs of job loss from innovation, this same government in the nineteenth century would react to wars, expanding trade, and the undesirable side-effects of industrialization and urbanization by increasing both the number of regulations *and* their enforcement.

Perhaps the British were simply more entrepreneurial than others. Beyond the fact that British society contained more upwardly mobile ethnic/religious minorities than other countries, it could be argued that in Britain social status was more readily gained by those who earned large sums in commerce or industry. In France, status was still accorded mainly to landowners and titleholders. However, titles and land were often bought by wealthy merchants in both countries. It has been suggested, moreover, that the ideal in Britain was the gentleman who earned large sums without working hard. This ideal would hardly be conducive to innovative effort. The overriding problem with entrepreneurial explanations is that only the successful entrepreneurs are generally observed. If France has fewer of these in the eighteenth century, we cannot be sure to what degree this reflects a shortage of entrepreneurs rather than a shortage of opportunities. Given that any British entrepreneurial advantage is not apparent either before or after the Industrial Revolution, we might suspect the latter.

Indeed, none of the arguments so far explains why industrialization occurred when it did. If we wish to explain the timing as well as the location of the Industrial Revolution, we need to isolate a factor that itself underwent some significant change in the eighteenth century. One such possibility is the transport system. Geography gave Britain a natural advantage here, but much work remained to be done. Until late in the seventeenth century, British roads had been the responsibility of the local parish, with local peasants being required to work a few days a year on the roads. Untrained and unpaid, these peasants did as little as possible; because there was no provision for maintenance, a significant rainfall could erase their work. These roads were unsuited to year-round use by wheeled vehicles. Turnpikes, on which tolls were charged to pay for road construction and improvement, were created to help improve the roads.[3] By the middle of the eighteenth century, England (and parts of Wales and Scotland) possessed a network of all-weather roads linking each town to every other. Companies that were formed to improve travel via rivers had doubled the length of navigable waterways between 1650 and 1750. Once the limits of river improvement were reached, canals were built to join the upper reaches of rivers recently made navigable. Although Britain had no official training school for civil engineers, private companies were able to call upon the services of a talented group of self-taught men. John Loudon MacAdam and Thomas Telford both invented new techniques for constructing gravel roads that could better withstand heavy traffic and inclement weather. The canals of James Brindley, which involved both extensive tunnels and long aqueducts, were among the engineering marvels of the time. Advances in eighteenth-century civil engineering would pave the way for railroads. By 1770, the principal industrial areas, sources of raw materials, and markets were linked by water transport. Transport costs per ton-mile were much lower by water, whereas roads were superior for speed, reliability, and geographic extent. No other country in the world had a transport system remotely comparable to what England had put in place in the decades preceding the Industrial Revolution.

The French government pursued an entirely different and much less successful transport strategy. Local roads (including many that would have been turnpiked in England) remained in the hands of unpaid peasant labor—the infamous *corvée,* a major complaint at the time of the French Revolution. Long-distance roads were guarded jealously by the government's Department of Roads and Bridges. A corps of highly trained engineers lavished vast sums on monumental bridges and left no money for maintenance; their roads, too, were often in miserable shape for much of the year. Travel diaries of the time are filled with horrific tales of ruts, rocks, and narrow passages; French stagecoaches traveled barely half the speed of their English counterparts. A similar saga unfolded on water: The French government would launch a major canal-building effort in the nineteenth century, without first having cleared the rocks and sandbars from the rivers the canals were to connect. They certainly possessed the necessary engineering prowess earlier; the seventeenth-century Canal du Midi had linked the Mediterranean Sea and the Atlantic Ocean and had involved, among other marvels, the first tunnel created by explosives.

Transport improvements significantly accelerated the processes of regional specialization and urbanization in England. They also led to a dramatic increase in personal travel. In the early eighteenth century, it was not unusual for a man to write his will before venturing from Birmingham to London. A half-century later the trip was much faster, more comfortable, and more reliable, and personal travel had become commonplace. Moreover, firms now faced greater competition, and thus had to be more interested in and open to new ideas. Not only did regional specialization ensure that people in given localities were well aware of the needs and potential of particular industries, but the growth of towns made it easy for those with ideas to interact with artisans who could build machines for them. Thus, Richard Arkwright drew on the supply of machine-makers in Nottingham to turn his idea for the water frame into reality. In various ways, then, transport improvements encouraged the interaction between innovators with varied backgrounds, expertise, and ideas, which is so essential to the innovative process.

Merchant-manufacturers in the early eighteenth century had spent up to a third of the year leading packhorse trains around to markets and fairs in order to dispense their wares. The skills required—and the danger, uncertainty, and volume of transactions involved—rendered this a task that could not easily be entrusted to a subordinate. With the revolution in turnpike roads, professional carrier services were established throughout England. Manufacturers in the decades around mid-century changed their methods of distribution in response. They sent out salesmen or distributed catalogs. They dispatched orders by carrier and received payment by carrier. The firm-owner was thus free to devote much greater attention to problems on the production side. One result was that the owner was much more likely to consider gathering his workers in a factory setting (we discuss the causes of the rise of the factory during the Industrial Revolution, and the huge impact this had on the course of innovation, in the next chapter). In general, industrialists who were freed from expending large amounts of time and effort in selling their goods naturally devoted greater attention to the possibility of innovating in the production process.

The changes in methods of distribution had a further crucial impact: whereas early-eighteenth-century entrepreneurs could benefit from having a range of goods to sell, those relying on salespeople with samples or catalogs could only satisfy their customers by producing standardized products. Customers wished to order and receive a good that looked exactly like the sample they had seen. It was difficult or impossible for artisans in their own homes to produce a highly standardized product. Entrepreneurs wishing to avail themselves of the potential of new methods of distribution thus faced a powerful incentive both to gather workers in factories and to mechanize production.

As industry concentrated in particular regions, it was only natural that workers in those regions came to specialize in the performance of specific tasks. These tasks, then, could be much more readily mechanized. In the iron industry, it had previously been the practice for small-scale ironworks to deliver iron rods to nail and needle makers, who would heat the rods and perform a variety of tasks to create nails and needles. From the mid-eighteenth century, slitting mills and wire works were established so that iron of the appropriate width for nails and needles could be given to these workers. Also, the twenty or so different tasks involved in nail or needle making were divided among different workers, and specialized tools developed as a result. By accelerating the division of labor, transport improvements had a further impact on the rate of innovation.

In various ways, then, we can see how transport improvements created an environment conducive to innovation in eighteenth-century England. The fact that no other country could boast a comparable network of both road and water transport, and that the transport system had undergone such a dramatic transformation in the early decades of the eighteenth century, appear to provide at least a partial explanation of both the location and timing of the Industrial Revolution.

American Backwardness and Receptivity to Change

In 1800, few would have predicted that the United States would surpass Britain as the world's leading industrial innovator within a half-century. As we suggested in Chapter 1, the new republic lacked almost all of the market and transportation advantages that encouraged Britain's mechanization. A mere 3.9 million people inhabited the United States in 1790, 18 percent of whom were slaves and two-thirds of whom were subsistence farmers. Moreover, so few people occupied a country the size of France (which had about 28 million inhabitants); and the United States soon was to be much bigger. Nearly giveaway prices for land in the 1790s (costing land companies as little as a half-cent per acre) encouraged a dispersal of farm population. This population hardly provided the makings of a mass market for industrial goods. In 1840, New England was only 12 percent as dense in population as England. Low population density seemed to assure that industry would remain local and unspecialized, and that farmers would continue to be relatively self-sufficient. Dispersed farms and towns only increased transportation costs. In the 1790s, the price of flour increased by nearly a third when it was shipped just 80 miles across the Virginia hills. Transport costs often negated economic advantages gained by mechanization and specialized production. In any case, many affluent Americans preferred the quality and variety of imported European goods.

In 1800, the United States also lacked the capital and skilled labor necessary for industrialization. Investment flowed into real estate speculation or overseas trade. This left little capital for industry. Moreover, by English standards, American labor was unskilled, and the frontier drained off a potential industrial workforce when young families were drawn to the promise of independence on a farm or with a craft.

Signs of American technological backwardness were everywhere in 1800. Americans were slow to switch to steam power, to adopt coke-fired iron refining, and even to exploit coal deposits. Ample supplies of water power, charcoal, and wood fuel explain this apparent inertia. Many Americans were content with their country being an agrarian nation. Thomas Jefferson glorified the independent yeoman farmer and decried the corruption and poverty that he thought inevitably came with the manufacturing city His antagonist Alexander Hamilton called for industry as the key to national greatness. But Americans were obliged to study railroad engineering in Europe and to lure European mechanics to build their factories.

Yet, in 1851 at the London Exhibition, American inventors—with their padlocks, reapers, and mass-produced guns—were the wonder of all. In 1854, a delegation of English observers traveled to the United States (in much the way that Americans would go to Japan in the 1980s) to discover the secrets of the 'American System of Manufacturing.' What explains this change? Over the next three chapters, various elements of this transformation will be explored, but a few general trends can be addressed here.

A key to what made an industrial America possible was the country's phenomenal population growth. The United States increased from about five million inhabitants in 1800 to approximately thirty million in 1860. This growth created a demand for household goods and farm tools. The population grew in Europe as well, but wage increases lagged behind productivity and rising land rents. This meant that demand for manufactured goods rose slowly in the Old World and food shortages in the 1840s (as in Ireland) wreaked economic havoc. By contrast, in the United States, population increases paralleled the expansion of the frontier. Abundant arable land meant both higher wages and relatively cheap food, which allowed for a larger share of household income to shift toward industrial goods (Figure 3.1).

Despite the problems of a dispersed home market, American producers had some protection from English exports because of the width of the Atlantic. The Napoleonic-era wars (1799–1815) also helped fledgling American industrialists to win domestic markets from the British (especially when, in 1807, the United States imposed an embargo on English goods). That advantage increased with the tariff of 1816, which protected an infant textile industry. None of this would have meant much if the development of the United States interior had not coincided with the 'transportation revolution' of turnpikes, canals, steamboats, and railroads (see Chapter 5). These improvements alone

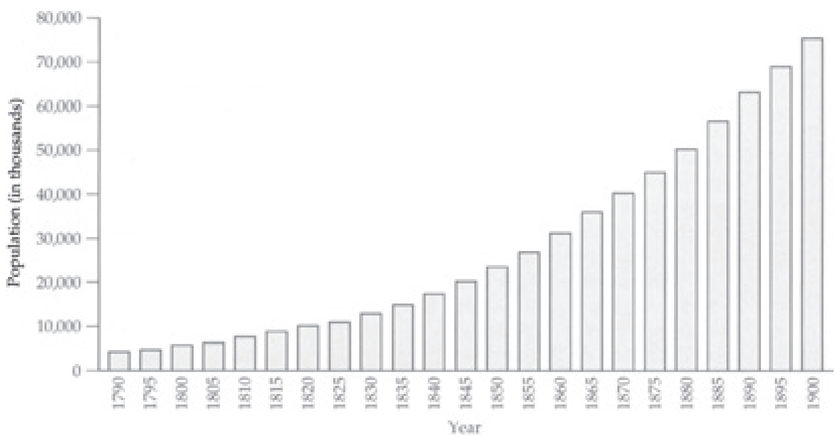

Figure 3.1 Growth in population was almost exponential.

made possible an integrated continental economy and spurred the transformation of a fragmented agrarian economy into a national mass market.

At the same time, the United States began to develop its capital, labor, and materials in ways that encouraged innovation. Business historians often stress how industrialization required new institutions and laws for mobilizing capital. From the 1780s, Americans copied English banking, insurance, and corporate practices for gathering money for commercial and manufacturing investment. American state governments were particularly innovative in corporate law. In 1811, New York State lifted the old rule, inherited from England, which required new corporations to obtain a special charter from the legislature. This measure, which was soon copied by other states, considerably eased the formation of manufacturing corporations. State legislatures soon provided relief from bankruptcy by gradually replacing imprisonment for bad debts with debt forgiveness. By midcentury, state governments introduced limited liability, a legal principle that freed investors in corporations from personal responsibility for the obligations of their corporations beyond the value of their investment. These changes encouraged risk-taking. As in England, American law tended to favor developers rather than inheritors of land. For example, from the 1820s, the states awarded turnpike companies the right of eminent domain, which forced landowners to sell, rather than block necessary road projects. State governments also occasionally subsidized manufacturers and founded schools to train workers from the late eighteenth century. The national government sought to gain access to patented British textile technology from 1787.

Probably the most crucial legal innovation was the Patent Law of 1790. Patents, rather than bounties or government subsidies, became the principal way in which government encouraged industry. Patents encouraged innovation by providing a legal monopoly over an invention (at first for 14 years from issuance, today 20 years from filing). The American patent system protected inventors, and it encouraged them to license or sell their patented machines or processes. At the same time, the strict granting of patent applications assured (in theory) that only new and useful ideas gained protection. Nonetheless, because it was hard to win patent infringement suits (as Eli Whitney found out when he tried to sue copiers of his cotton gin), inventions were quick to pass into the competitive market. On balance, the American legal climate was conducive to industrial capital and innovation.

Although advocates of industrialization (such as Hamilton) often complained of the cost and scarcity of American labor, this disadvantage turned into a benefit. While in the South chattel slavery resolved the problem of scarce white labor and created a plantation economy, high-wage labor in the North encouraged manufacturers to substitute machinery for expensive workers. Scarce labor had other advantages to northern manufacturers: Low population in relationship to quality land helped to create a large class of affluent family farmers, especially in the upper Midwest. They were neither subsistence producers (as often in Europe) nor aristocrats relying on high rents and cheap or slave labor. These farmers with their relatively large and fertile land with increasing access to markets nevertheless lacked cheap or reliable labor to exploit their holdings. Thus, they had a strong incentive to employ labor-saving machinery to maximize the quantity of land that they could cultivate. This was an obvious spur to agricultural tool manufacturing, and to food and raw material processing industries (like flour and lumber milling).

Another effect of labor scarcity was the fact that American industrial workers were less likely to resist mechanization than were their skilled European counterparts. While English and continental European workers sometimes sabotaged machinery, fearing the loss of their jobs, Americans did not. Sometimes machinery increased the wages of this scarce American workforce rather than displace it. In any case, American workers who were made superfluous by steam presses or grain reapers often could find alternative jobs 'down the road,' even if frequent economic depressions disrupted their lives. American workers were comparatively less reluctant to move, and they frequently shifted between self-employment and wage work. Thus, they had less personal stake in any given skill or set of tools than did workers in England, who often remained in a single trade for life. Moreover, American Jacks-of-all trades were more flexible when encountering innovation than were British crafts workers because they had less commitment to particular ways of work. For all of these reasons, it is not surprising that American workers adapted to and even initiated innovation. For example, American farmers who worked temporarily on canal construction in the 1820s and '30s developed a horse-driven bulldozer. This amazed British observers, who were used to laborers who tried to slow the pace of work to stretch out the length of employment. Finally, after 1840, new waves of landless and poor immigrant labor (especially from Ireland) were put to work on machines. Native-born Americans coming from crafts often found jobs in supervision or machine construction and maintenance.

Americans also had significant advantages in the supply of raw materials. A prominent example was access to cheap green seed cotton, especially after the coming of the cotton gin in the 1790s, which efficiently separated the seed from the fiber. The cost of American cotton to New England manufacturers in 1815 was half the price paid by their English competitors.

American advantages in natural resources sometimes led to waste in efforts to save labor costs and increase speed. A good example is the American circular saw, which wasted much wood (in sawdust) but was far faster and required far fewer workers than did the old pit or vertical mill saws. Early on, circular saws simply were not cost-efficient in England, where lumber was far scarcer. Cheap raw materials combined with costly labor and transportation led Americans to develop time-and labor-saving technologies in wood as well as in transportation and communications (steamboats and telegraphs, for example).

Sometimes natural resources encouraged Americans to retain 'backward' technologies. The United States had an advantage over the British in fast-moving streams and rivers. This waterpower, as we have seen, was the source of much labor-saving machinery operated by waterwheels in rural colonial

America. But water also powered important centers of manufacturing from Delaware to New Hampshire for more than sixty years after 1790 despite the availability of steam engines from England. For years, water wheels were cheaper. For the same cost advantage, Americans were slow to abandon wood in both construction and iron furnaces (sticking with charcoal over coke). On balance, however, Americans quickly adopted European technology and innovated where economic factors encouraged it, especially in wood, transport, and communications industries.

Cultural factors also help explain American receptivity to innovation. Americans may have been prone to invent machines merely because they were free from loyalties to traditional ways of life and willing to adopt any that was useful. Benjamin Franklin's observation is typical of this pragmatism: "A discovery which … is not good for something is good for nothing."[4] His simple but practical stove insert into the fireplace saved fuel and increased efficiency in heating rooms. His lightning rod reduced fires. Thomas Jefferson was also noted for his useful ideas, including the national adoption of the decimal monetary system, replacing the old and complicated English coinage system. In the 1790s, Alexander Hamilton even recruited English artisans and imported British textile technology, believing that the imitation of English industrialization was the only way of ensuring future American independence and greatness. This practical perspective led Americans to develop a widespread elementary education system. By 1850, a far higher proportion of white American children attended school than elsewhere.

Early-nineteenth-century Americans had great advantages. Increased population in a resource-rich land created markets for industrial goods; the legal and political system encouraged the growth and risk-taking of capitalists; the American workforce did not impede and sometimes even encouraged mechanization; and American culture was hospitable to innovation.

Still, American industrialization was neither easy nor did it come without the vital help of others. First, only a dramatic improvement in transportation would make industrialization possible in America. As we noted in Chapter 2, some Americans had the advantage of a useful regional waterway system. These watercourses linked the coasts with the interior and extended from the Hudson and Mohawk rivers in the North to the Potomac and Savannah rivers in the South. The Ohio and Mississippi river systems made possible the early colonization of the vast lands beyond the original thirteen colonies and fostered the development of a national market. But like Britain, it would only be with the building of a system of interregional roads, the construction of canals, innovations in riverboats powered with steam, and—of course—railroads, that Americans could fully industrialize.

Moreover, we cannot ignore the debt that the new republic owed to European skills and technical knowledge. British immigrants brought much technical knowledge (including that of the millwright and machinist) that was essential for American industrialization. British experts were critical to the development of Pennsylvania's coal-mining industry in the 1820s. The early American chemical and pharmaceutical industries owed their origins to Swiss, English, and German immigrants. Newcomers also brought useful attitudes. Immigrants were a self-selected group, willing to abandon old family and social ties for the prospect of individual gain in the still-primitive conditions of the early republic. Such people were especially apt to accept and participate in industrial innovation.

Finally, Americans—like other later entrants into the industrial revolution—had the advantage of following on the experience of innovators. In the first decade of the nineteenth century, American manufacturers regularly visited Britain to gain information about textile technology and did the same in the 1830s to learn about locomotive construction. This borrowing obviously saved research and development costs. Moreover, as a second-generation industrializer, the United States could start with more advanced technology, as it did in the textile industry.

The first industrialization was in large part an invention of the British. Yet it quickly passed to their American offspring. In the process, though borrowing from Europe, the United States developed its own particular forms of innovation.

Notes

1 A further consideration was the fact that England had not seen a serious military invasion since 1066 (though there had been a lengthy Civil War in the seventeenth century, and a Jacobite invasion in the mid-eighteenth). Continental entrepreneurs had greater reason to fear the depredations of armies on the move.
2 Epstein, S. R. "Craft Guilds, Apprenticeship and Technological Change in Preindustrial Europe," *Journal of Economic History,* September 1998, 684–713.
3 Turnpike trusts were granted two other important rights. They could borrow money to finance construction, and they could expropriate land (with compensation) that lay along the preferred route.
4 *The Ingenious Dr. Franklin* (selected letters), edited by Nathan Goodman (Philadelphia, 1931), 19.

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4 The Birth of the Factory

The phenomenon of the modern factory is unprecedented in human history Before the late eighteenth century there were no buildings housing lines of machines, churning out thousands of identical products with the aid of human attendants. The factory's origins can be most readily traced to textile manufacture, although factories emerged simultaneously in other industries. Factories might seem to have developed naturally from new technology, but centralized workplaces had separate origins. The textile factory symbolized a new age to many Europeans and Americans. It promised limitless economic growth, but also threatened to undermine the dignity of work and the cohesiveness of family life based on shared labors. But even if these early mills were islands of mechanization in the seas of agrarian and craft society, they were linked to the traditional world of work and family. These factories originated in Britain, but they were adopted quickly by Americans—although with distinct features peculiar to the early United States.

Simple Machines Produce Amazing Results: Cotton Textiles in Eighteenth-Century Britain

Textiles, and especially cotton textiles, have been among the first industries to mechanize in many countries, including Britain during the Industrial Revolution. This is due in part to the simple nature of the technology involved, and the market for textiles that exists even in poorer countries. The most basic of textile products must still pass through a number of stages of processing between raw material and final product. Cotton, after preliminary cleaning and sorting, had to be carded so that the fibers were straightened and laid side by side. Then, the fibers were stretched and straightened further into 'rovings' before they were ready for the spinning process, in which rovings were pulled and twisted together to form a strong thread. Threads were then woven, bleached, and usually either dyed or printed before being ready for sale.[1] We discussed in Chapter 2 the traditional methods of textile production employed in colonial America. During the second half of the eighteenth century, significant advances were made at each stage of processing.

These stimulated the rapid growth of the British cotton industry and gave British and foreign consumers access to lower-cost and higher-quality cotton goods. Within decades the wool and linen industries adopted most of the technology created for cotton, although both the characteristics of these other fibers and the resistance of workers in these more traditional trades acted to impede technological advance.

As we have seen, carding was traditionally performed by holding in one hand a card with metal spokes sticking out and pulling the cotton through the spikes with another card held in the other hand. The first improvement was to attach one of these cards to a table so that one worker could work a set of these cards with each hand. Early in the eighteenth century, it was recognized that fixing the cards to a rotating cylinder allowed workers to handle four or five pairs at a time. Just before mid-century, the first attempts at complete mechanization occurred. These relied on the use of cylinders. The first machines were not commercially successful, but numerous inventors were stimulated to make minor improvements. The concentration of cotton manufacture in Lancashire, and of card-making in the nearby Calder Valley, greatly facilitated the interchange of ideas. In the 1770s, Richard Arkwright brought a number of these improvements together, and added the cab and crank for taking the cotton wool off the machine: This made continuous operation feasible.

By lowering the cost of the final good, innovation at any one stage of processing naturally stimulated innovation at other stages (as did decreases in the costs of transport and distribution). Historians have often suggested that advances in spinning were a response to midcentury advances in weaving (especially the so-called flying shuttle on the manual loom). The challenge-and-response theory posits that the decreased cost of weaving created a bottleneck in spinning that encouraged innovative effort. A real bottleneck, though, cannot last forever, for eventually more workers will be trained as spinners to meet the increased demand for spun yarn (the predominance of men in weaving and women in spinning would obstruct the transfer of workers from one stage to the other). Given that the innovations in spinning were the result of decades-long efforts by many hands, we should be hesitant to attribute this effort entirely to the shock of one innovation elsewhere.

Indeed, the first efforts at machine spinning predate the widespread use of the flying shuttle in weaving. Lewis Paul had experimented with replacing the spinning wheel with rollers before midcentury; he took out a patent in 1738. Pairs of rollers placed a few inches apart and moving at different speeds could stretch the fibers; the twist could be imparted by setting the receiving bobbins at an angle. The idea was present early, but the application was difficult. Traditional spinning wheels had allowed skilled operators to adjust the speed so that rovings of varied thickness could be stretched and twisted simultaneously. If rollers were used, rovings of even diameter were required. Only after improvements in carding could this advance in spinning become practical.

As with carding machines, numerous minor improvements were made in successive decades, and again it was Arkwright who put these together. He placed the rollers the appropriate distance apart so that threads were stretched but not broken, and he weighted them so that the twisting motion did not run through the rollers (fibers were much more likely to break if they were twisted while passing through the rollers). It cost Arkwright more than £12,000 to perfect his 'water frame,' a sum he could not have raised if local manufacturers had not seen the potential of his device. Arkwright's spinning machine was patented in 1769; by 1780 there were 20 water frame factories. After Arkwright's patent expired in 1785, this number grew to 150 by 1790.

Although Arkwright's spinning machine could have been used in cottages and powered by hand, he only licensed it for use in factories where water could power it. It was suited only to the strongest of cotton fibers. James Hargreaves's spinning jenny had preceded the water frame by a few years (he invented it in 1764). It remained the only machine capable of dealing with the more delicate cotton goods. We know little of the development of the jenny. But it was an attempt to replicate the spinning wheel, with the wheel turned on its side and made much smaller. The fibers would be stretched as long as the receiving bobbins were moving faster than those on which the yarn had been wound. Hargreaves had recognized that the wheel itself could impart the twist to the thread if the yarn were guided correctly onto the spindle. Over time, the spindles and wheels on a jenny were increased in number from a handful to hundreds (Figure 4.1).

The next step was the combination of jenny and water frame in Samuel Crompton's 'mule.' Spindles mounted on a carriage that moved back and forth turned quickly and shared with sets of rollers the task of imparting twist to the thread. Because the strain on the yarn was minimal, this device could be used to spin fine threads that were both strong and inexpensive. Crompton spent five years working on the mule. When it was complete in 1779, it was still an imperfect piece of artisanship; many turned their hand to improving it in succeeding years. Crompton's wooden frame was replaced with iron, and the gearwork that controlled the rollers was enhanced. The number of spindles per machine tripled in the last decade of the eighteenth century. The mule, with many subsequent improvements, was to be the mainstay of the British cotton industry through the nineteenth century (and within decades would displace the jenny and the water frame for wool as well).

While these three breakthroughs were being developed for spinning, there was relatively little advance in weaving.[2] Kay's flying shuttle, introduced in 1738, had become widespread in both cotton and wool production from the 1760s on. Weaving is a simple operation in principle: Alternate threads in the warp are raised while the weft is passed through in one direction; then the other warp threads are raised while the weft passes in the other direction. The flying shuttle mounted the weft thread on a shuttle that the operator could cause to move back and forth by pressing a foot pedal, and thus allowed one

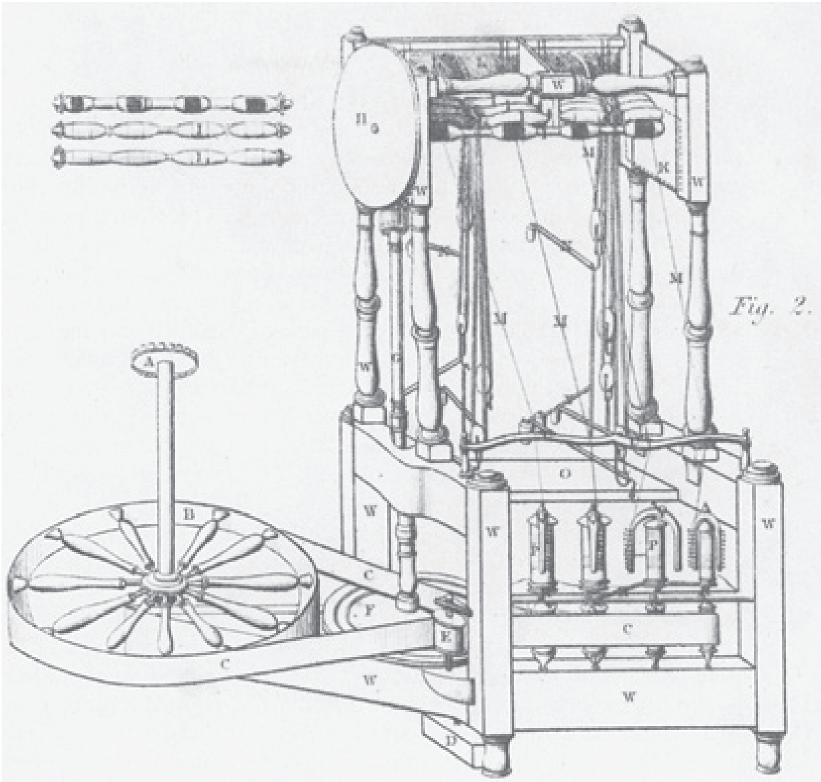

Figure 4.1 A drawing of Arkwright's spinning machine (1769). Notice the rollers at the top.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

worker to do the work of two (previously, a small boy had been employed to run the weft back and forth).

Many turned their thoughts to replacing this worker as well in the late eighteenth century. Before the loom could be automated for cotton, however, another technical hurdle had to be overcome. Cotton thread tended to snap during weaving unless coated with a glutinous material to cement the fibers together. Until the 1780s, the loom had to be regularly stopped for this purpose. Once a method was discovered for coating the threads before weaving began, the incentive to develop a fully automatic loom was greatly enhanced. Richard Cartwright produced such a machine in 1787, but it was so prone to breakdown that one operator was still necessary for every two machines; decades of improvements were required before the automatic loom saw widespread commercial application.

Although it took only hours or days to spin and weave, it took six to eight months to bleach cotton cloth in the early eighteenth century. The fabric was repeatedly placed in a bleaching solution and then hung in the sun to dry. This was both time and land intensive, and the shortage of bleaching grounds must soon have halted the phenomenal rise of the cotton industry. In the 1750s, sulfuric acid was introduced to the bleaching process. The acid was produced in large-scale chemical works that replaced glass vessels with lead, cutting the cost of the acid to a fraction of its former level. This cut bleaching time in half. The Swedish scientist Carl Scheele discovered chlorine in 1774, and the French scientist Claude Louis Berthollet established its usefulness for bleaching in 1785. After that, English bleachers undertook a series of costly on-the-job experiments. Chlorine reduced bleaching time from months to days. At the end of the century, bleaching powder was introduced, so that individual bleachers no longer had to produce their chlorine.

Dyeing often cost more—and required more raw materials by weight—than spinning. Although still reliant on natural substances, trial-and-error experimentation produced superior red, green, and yellow dyes in the second half of the eighteenth century. Most cotton goods were printed, and this final stage of processing also experienced numerous improvements. As the scale of printing operations expanded, long-lasting copper plates replaced wooden blocks. Still, block-printing remained tedious: A 28–yard-long cloth required 448 precise applications. In 1785, the first cylinder printing device was patented. This machine resulted from years of experiment by many hands and needed additional years of effort before it too gained widespread use. With it, one worker and a boy could replace a hundred workers.

From Cottage to Factory: Causes and Social Consequences in Britain

It would be only natural to suspect that the technology discussed in the previous section provided the inducement for the emergence of the factory. As machinery became larger and more complex and came to be powered by waterwheels or steam engines rather than by hand, one might expect that it would come to be located in centralized workplaces. Cottages would have neither the room nor the access to power; workers would have to follow the machines to the factory. Certainly, as the Industrial Revolution progressed, technological developments would greatly encourage factory production. It is clear, though, that in the all-important early days of the Industrial Revolution, the first factories used technology that was similar to that used in cottages. This not only indicates that some other forces must have been at work to bring about the factory, but also suggests that technological innovation may have been more a result than a cause of factories. Once factories existed, innovators naturally turned their attention to more powerful machines that would not have been feasible in the cottage setting. A great deal of technical advance resulted from simple attempts to hook machines together and attach them to external power sources.

Before 1750 one can, to be sure, find some examples of production occurring in a centralized manner. Shipbuilding and sugar refining had never been performed in the home for obvious technical reasons (or not so obvious, given that many ironworking tasks, such as nailmaking, were conducted in the home). Governments had occasionally sponsored workshops that produced high-quality luxury goods (such as Gobelins tapestries in France), or military goods. But such enterprises depended for their success on government support rather than productive efficiency. Before 1750 there were virtually no large-scale industrial works set up by entrepreneurs without government support and based on a decision that factories could produce cheaper or better goods than those produced in the home.

After 1750, in Britain, many entrepreneurs gathered workers together, not just in cotton but in metalwork, pottery, and wool as well. These factories dotted the English countryside decades before Hargreaves developed the jenny, James Watt the separate condenser steam engine, or Henry Cort the pudding and rolling method of iron manufacture.

Why did entrepreneurs move toward factory production after 1750—and only in Britain? One conventional explanation is that factories allowed employers to exploit workers better. In the factory setting workers could be forced to work long hours for low wages, whereas in their own homes they were masters of their own time. To be sure, workers were hesitant to give up their freedom, and many stayed in their cottages for decades even as piece rates fell. It was their children who would take up factory employment. Still, the life of the cottage worker should not be idealized. We do not know how many hours workers had previously worked at home, but there is reason to believe that total hours worked were not much different in home or factory. We must also ask how the earliest entrepreneurs were able to lure any workers into this exploitative relationship. Once factories came to dominate industrial production, workers may have faced little choice, but this would seem not to have been the case at the very beginning.

A more benign argument is that factories were merely a more efficient form of organization. Entrepreneurs who employed workers in their own homes, in the putting out system, suffered in many ways: they incurred transport costs in moving raw materials to homes and furnished goods back; workers often embezzled their materials; dispersed workers could not produce a standardized product; and it was impossible to respond to changes in fashion quickly. Employers, then, preferred factories not because of a desire to exploit workers, but mainly so that they could exercise more control over the productive process. Yet cottage production also had its advantages: it was more flexible so that if demand dropped production could be cut back readily (there was little capital invested, and workers could seek temporary employment in other sectors), and employers did not have to supervise and feed their employees.

Neither the exploitation nor efficiency arguments address the question of timing. If the factory had always been advantageous, we would have to wonder why cottage production had survived for centuries. It was not because nobody had thought of the idea of the factory for, as we have seen, there were many examples of factories before 1750. The fact that entrepreneurs had not previously copied the government-sponsored works must lead us to suspect that factories were not advantageous before 1750. Something must have changed to make them so.

We have already discussed the dramatic changes that occurred in the British transport system over the course of the eighteenth century. If we imagine a 'typical' entrepreneur trying to decide between factory and cottage production, there are many ways in which transport improvements would tip the balance toward the factory (only a few of which we discuss here). In some industries, access to wider markets would be an important consideration. As transport costs fell, a greater variety of raw materials could be used: Buckle makers, for example, who had previously used just iron and tin, came to use copper, brass, zinc, glass, and alloys imitating gold and silver. This increased the difficulties of carrying materials to workers, and severely exacerbated the problem of embezzlement. As transport costs fell, industries became concentrated in particular regions, as low-cost producers there were able to invade the markets of inefficient local producers elsewhere. One natural result was a division of labor: Workers came to specialize in one operation rather than performing many distinct tasks. Entrepreneurs now were forced to arrange for the movement of semi-processed goods between houses. Although it might seem that falling transport costs should have eased the problem of transporting goods to workers, they served in important ways to worsen this problem.[3]

We noted earlier that cottage production was inherently more flexible. A factory manager would have to worry about keeping his capital stock and regular working force steadily employed. But as speed and reliability of transport improved, the size of raw material inventories necessary for this purpose declined. On the output side, entrepreneurs were able to take advantage of the nationwide system of professional carriers that emerged as the roads were made capable of supporting year-round wagon movement. Whereas entrepreneurs had previously spent months on the road leading packhorse trains to fairs and markets, around 1750 they began to send out catalogs or salespeople with samples, receive orders by mail, and distribute goods by carrier. This had two effects: first, it freed entrepreneurial time for the supervisory tasks which the factory entailed;[4] second, it forced entrepreneurs to produce the standardized output expected by distant customers, and cottage workers just could not do this.

These trends encouraged early entrepreneurs to set up centralized workplaces that employed precisely the same technology used in the home. Once factories were in place, however, innovators often turned their minds toward technology suited to the new setting. Once many looms were gathered together in one building, inevitably they were joined together and attached to an external power source such as a waterwheel or, later, a steam engine. It is not surprising that innovators had not previously developed technology entirely unsuited to cottage production. Instead, once the factory was in place for other reasons, the technological potential of this new setting was gradually explored. As large externally powered machinery grew in importance, factories became even more advantageous.

The centralized workplace did not at first emerge in the large cities. Industry had for centuries been located in the country, and both water power and cheap labor could readily be found there. Only after factories came to require an extensive pool of both skilled and unskilled labor, as well as access to repair facilities and other services, did factories begin to concentrate in new industrial centers. Even more importantly, the shift from rural waterwheels to steam engines as an industrial power source facilitated the emergence of industrial cities like Manchester and Birmingham. Ramshackle worker housing surrounded these factories. Those countries like the United States that strove to catch up to Britain technologically in the nineteenth century also attempted to avoid these unsightly slums.

The factories changed the meaning of labor. Even if hours worked were roughly the same in factory and home, wage-earners lost control over the pace and methods of their work. Home workers were legendary for extending their weekend drinking into 'Saint Monday,' and then madly trying to make up for lost time later in the week. Constant supervision was also a novel experience, at least for the head of household. Even though families often worked together in the first factories, something was nevertheless lost with respect to family togetherness. It is clear that a wage premium had to be paid in factories to entice workers into that setting. Even with that, most cottage workers (especially handloom weavers, who were the most studied of these) chose to stay in their homes. Men, especially, mostly avoided factory work in the early nineteenth century. As factory production grew, such home workers saw their earnings shrink. The following generations would find their choice tipped much more heavily toward factories.

British factories themselves were dark, dusty, and poorly ventilated. The cities in which they came to concentrate were overcrowded and polluted, and thus natural breeding grounds for communicable diseases. Although one should not romanticize the rural huts of poor cottage workers, it is clear that cities had always been unhealthy, and became more so during the Industrial Revolution. Most workers who abandoned rural labor for life in the factory lowered their life expectancy and that of their family.

The increased innovation and the emergence of factories, which together constitute the Industrial Revolution, would cause British per-capita incomes to rise at unprecedented rates after 1820. However, at least in the eighteenth century, that revolution made much of the British working class worse off. Real wages stagnated, while workers sacrificed freedom, health, and family.

Such a transformation naturally had an impact in the political arena. Workers in their rural cottages had been a weak political force. Gathered in factories and concentrated in cities, they could not be so easily ignored. They soon gained a collective identity and an interest in improving their collective lot.[5] Worker agitation was a dominant force behind a number of reforms in the nineteenth century, including the extension of the right to vote to working-class males; legalization of unions, strikes, and collective bargaining; and industrial safety and child labor laws. Many of these initiatives spread to other countries along with the technology of the Industrial Revolution, and helped these countries evade some of the excesses of English industrialization—Continental political leaders of various ideological stripes would rejoice that they had nothing like the slums of Manchester. This hostility to the English pattern also made it somewhat more difficult for other countries to catch up to England, to the extent that their workers and farmers agitated against further changes in technology or organization.[6]

Americans Learn to Compete: From Samuel Slater to Lowell Mills

Soon after independence from Britain, American merchants dreamed of manufacturing textiles. The financial rewards of the transatlantic trade were dwindling. With nationhood, American exporters faced import duties on most products sent to England, and Yankee shippers lost their old privileged status in the British Empire. Americans had little difficulty in 'borrowing' English textile technology. The machines were simple, requiring little more than the woodworking skills that abounded in the United States. As early as 1774, a decade after Hargreaves's invention, an English immigrant made two spinning jennies in Philadelphia. Thomas Digges, a disgraced son of a wealthy Maryland family, with a past of double espionage during the Revolution, turned his penchant for intrigue to the art of smuggling; he brought about twenty English textile-machine makers to the United States. Several went to work for Alexander Hamilton.

Nevertheless, a shift to manufacturing posed distinct disadvantages to Americans: in 1790, there were only 2000 spindles in the United States, compared to the 2.41 million spindles in Britain. Americans had yet to adopt sophisticated water-frame or mule technology. Because English textiles were light in weight relative to their value, transportation charges for export to the United States were not so burdensome as to make them uncompetitive. Thus, few American manufacturers were successful in challenging the glut of English exports that flooded the United States between 1793 and 1807.

An exception, however, was Samuel Slater (1768–1835). Born in the English textiles district of rural Derbyshire, the young Slater was apprenticed to a local manufacturer to learn how to manage a mill. After six years of training, he immigrated in 1789 and was hired by a New York workshop to construct spinning jennies. Soon after that, he read an advertisement from two merchants, William Almy and Moses Brown of Providence, Rhode Island. These investors were seeking a mechanic capable of running some old spinning equipment to supply yarn to local weavers. Slater demanded and won a partnership with Almy and Brown. In 1793, he built water frames and carding machines from memory. In an old clothier's shop in Pawtucket, his spinning mill employed nine children between the ages of seven and twelve. These young workers labored daily 12 hours in winter and 14–16 hours in summer. This use of juvenile workers was not unusual. Few families felt that they could survive or prosper without the labor of their children.

Slater carefully followed traditional hiring practices. Because fathers resisted work in the mills (considering it humiliating), Slater offered them employment as watchmen and construction workers, jobs deemed appropriate for men accustomed to the freedom of outside labor. Only then did these men allow their children to work in the mills. Slater accepted these fathers' exercise of their patriarchal rights to intervene in the discipline and protection of their working children. Married women remained at home.

Though Slater brought British technology, he nevertheless depended over time on local artisans to build and then improve these machines. He thus benefitted from the longstanding existence of a domestic textile industry and local machine-making capability. Note also that Slater's move to the United States, and then to Providence, was predicated on the prior existence of a cotton industry. As in Britain, success in mechanized spinning depended on mechanization of carding: Slater would rely on a local cardmaker, Pliny Earle, to improve his carding machines.

Though Slater built a business empire around cotton and woolen spinning mills, he still placed them on streams near local rural labor supplies. He supplied his workers with cottages and household needs, deducting rent and purchases from weekly pay. Slater built churches in the hope of instilling habits of temperance and duty to work; Sunday schools taught punctuality. In many ways, this paternalism eased the transition from rural to factory work and way of life.

His factories very much reflected American conditions in the 1790s rather than those of England. Textile mills in Manchester, England began to install steam engines in 1786; but American imitators, like Slater, stayed with the waterwheel and rural factories. American production remained small (with Britain possessing 60 times the number of spindles as the US in 1810). The American weaving industry depended on the looms of farmers, a dispersed labor force which was seldom willing to work throughout the year. This would soon change with the increase in cotton fiber thanks to Eli Whitney's invention of the cotton gin in 1793 (Figure 4.2). Some mill owners began to force their cottage weavers to work in factories, where their employers could control their productive hours. But the long-term solution was further mechanization.

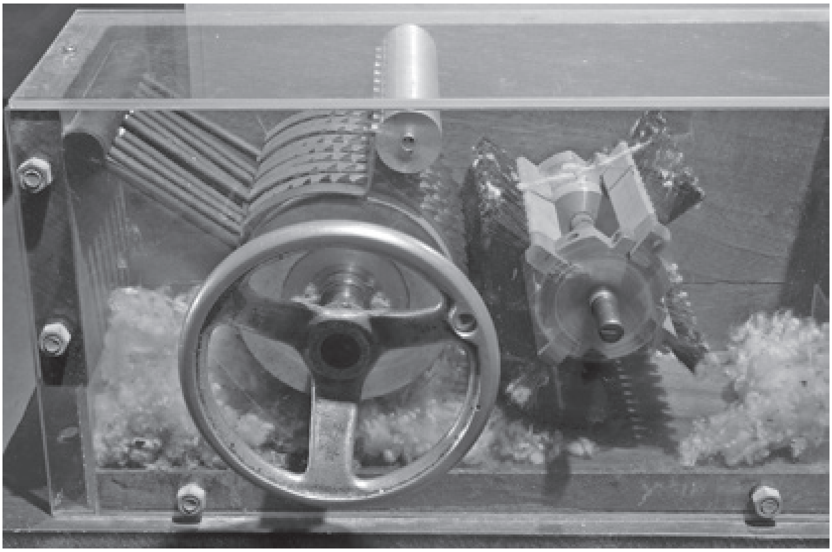

Figure 4.2 The cotton gin of Eli Whitney.
Credit: *Eli Whitney Museum.*

A second stage of American textile industrialization took place in Massachusetts in the 1810s. Its pioneer was Francis Cabot Lowell. Unlike Slater, whose life was the factory, Lowell began his career in the transatlantic trade and as a speculator in land and bulk commodities. On a trip to England, he observed mechanical looms, probably making detailed notes of what he saw. Upon his return to Boston, he had a local mechanic build an imitation. In 1813, Lowell formed the Boston Manufacturing Company (BMC) with eleven other investors and produced a coarse but cheap cloth that appealed to the American frontier market. The 1816 tariff of 25 percent on imported textiles also helped the fledgling Boston group to compete with the British. After Lowell's death in 1817, the BMC sold stock, and in 1821 bought land and water rights along the Merrimack River for further expansion. The results were dividends of 17 percent in 1817, which rose to 25 percent in 1824 and 35 percent in 1825. The mill town of Lowell, built in 1825, became a model of large-scale industry in the US. Ownership and management became separate (in contrast to Slater's conservative family management). By 1830, Americans had roughly a third of the spinning capacity of British, and they were rapidly closing the gap.

The BMC factory at Waltham, Massachusetts, combined spinning and weaving (while these tasks remained separate in Britain). The BMC soon operated a factory that employed ten times as many workers as the Slater mills. Each process—from cleaning, carding, and spinning, to weaving—was carried out by machines in the same building and under the close supervision of overseers. These Massachusetts innovators abandoned Slater's child (and family) workforce for young farm women. Faster machines and the desire to eliminate the informal influence of the parents of mill children may account for the switch to an older more homogeneous workforce. Unlike the British who continued to use mule spinning machines (which required heavy pulling and pushing by adult men), the American water-frame machinery allowed for a labor force consisting mostly of young females. By 1835, the mills of the Boston manufacturers employed 6000 women.

The machine—and the market—dictated the pace and methods of work. As importantly, these machines were centralized in a factory. This forced weavers to accept employer's schedules and to abandon farm and other work that interfered with regular hours of weaving. Twelve-hour workdays for 309 days a year were typical. Factories often had a central bell and clock tower, under which was a gate that strictly controlled access to the mill. The clock was symbolic of the new emphasis on punctuality and time discipline. Work was simple and repetitive: Mill hands pieced together broken yarns on the spinning machines; weavers did the same and replaced bobbins when they ran out (Figure 4.3).

However, American textile mills in the 1830s and '40s were probably more traditional than were British factories. Unlike the increasingly steam-driven and urbanized factories in Britain, American mills continued to be located on streams and rivers in rural villages. Typical was the mill hamlet of Rockdale, Pennsylvania, with its population of mill workers living in proximity to owners.

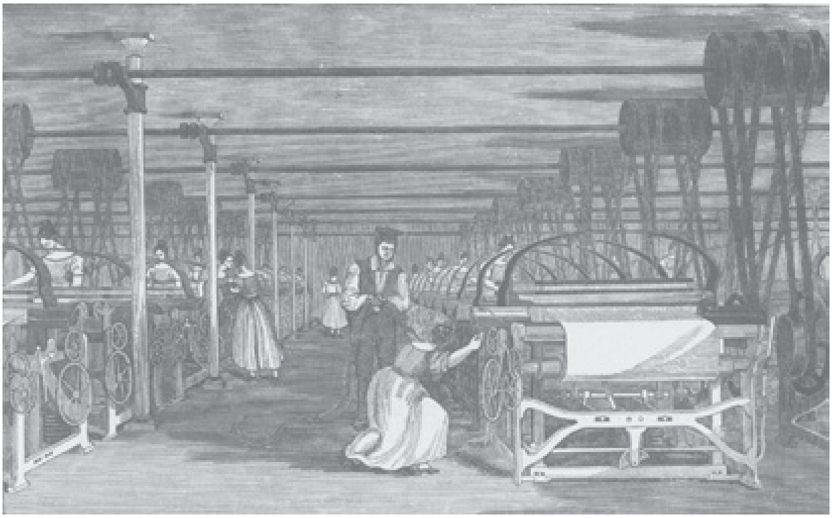

Figure 4.3 Women working at power looms, similar to those found at Lowell.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Employers were less competitive and less technologically sophisticated than one might suspect. Mill-owning families were often related to each other; they found 'places' at the mills for failed members of their social class. Managers may have lived on the hill rather than near the noisy mill with the laborers, but they often attended the same churches as did their workers, and they often knew their laborers personally. This added a dimension of paternalism to the work life of rural mills that would disappear with the coming of the larger urban factory. Management, for example, strived to eliminate drinking, gambling, and smoking on the job. Families were often able to find employment for their members and to work closely with one another. Because offspring worked in the mill and housing was cheaply provided by the mill owner (to guarantee a stable workforce), mill hands were often able to save substantially. For example, in 1849, one Rockdale family was able to keep $122.49 out of an annual income of $426.46. This meant that these families sometimes could escape the mill after a few years, to buy land or enter a trade as an independent craftsperson. They were hardly the proletarians condemned to a lifetime chained to the machine that Karl Marx described.

The Transformation of the American Textile Mill: Women and Immigrants, 1810–1850

From the 1820s through the 1840s, the Massachusetts textile mill symbolized the American factory, which often was contrasted with the 'dark Satanic mills' of England. The 'Lowell System' created a disciplined but respectable workforce. In one mill, the female workforce constituted 85 percent of the total, 80 percent of whom were between 15 and 30 years old. As mostly daughters of relatively modest, but respectable, farmers, they were hardly the downtrodden. Few of their families seemed to rely on their daughters' earnings for survival. In many cases, their savings became 'dowries'—income that attracted ambitious prospective husbands. When they worked in the mills, these young women were merely adapting the old custom of single women taking jobs as domestic servants or farm hands in order to save for marriage. In this case, the mill's wages were an especially lucrative option. Many of these Lowell women moved from farm backgrounds to urban trades upon leaving the mill and marrying. Still, most were not individualists—they came and worked with other relatives in the mills.

European visitors regularly stopped to admire the cleanliness and civility of the unmarried female workforce and their company-run boarding houses. This boarding arrangement was essential because of the distance from populated areas. Moreover, parents of these young women insisted that the company provide a protected environment for their children. The matrons who controlled the boarding houses of the 'factory girls' encouraged punctuality and hard work and discouraged drinking and rough language. Weekly church attendance was expected. Freed from the obligations of family, these young women could be trained to work by the clock. But the dormitory-style living arrangements encouraged social and cultural contact between the female 'hands'—even if they worked 73 hours per week. In 1842, Charles Dickens wrote in glowing terms of their libraries, the poetry in their magazine, *The Lowell Offering,* and their piano recitals. He compared these bright conditions with the English mills in which children continued to be exploited.

But, already in the 1830s, as the BMC patent protection ended, increased competition and sharply declining prices for manufactured cloth led employers to cut wages. Textile workers, facing increased workloads and lower wages in the 1840s, joined a movement for a ten-hour workday. This led to the unexpected—a series of strikes led by young women workers. Female strikers justified this 'unladylike' behavior by evoking the memory of their ancestors, the farmers who fought the Revolutionary War against aristocratic despotism. They did not see themselves as oppressed proletarians but as defenders of 'republican liberty.'

In response to labor unrest (and increased demand for coarse cotton cloth), the New England textile industry sought new sources of labor. Finding native-born women both too demanding and insufficient in number, employers sought immigrant workers from Ireland and French Canada. The percentage of immigrants in one company rose from 8 percent in 1845 to 60 percent in 1860. The old paternalism of the boarding house matron declined and eventually disappeared. Whole families worked for low wages and lived in rented tenements. Immigrants were often placed in poorly-paid jobs in carding and spinning, leaving more lucrative posts in weaving to Yankees. Young people were expected to contribute their wages to their parents for the survival of their families. By the 1860s, about 65 percent of the immigrant family's income came from children. The fact that daughters often contributed ten years of wage labor to their families was the source of much family conflict: The young sometimes ran away or fought with parents over spending money. These changes dramatically altered the meaning of work in the American factory. Factory jobs may have been better than what immigrants were used to, but—by the 1860s—the American mill became more like the English factory decried by Dickens than the enlightened model factory of the 1820s.

Nevertheless, we should not forget that work in British and American textile mills was the exception rather than the rule, even as late as 1850. The factory appeared to be the future, and indeed for many it was. But the range of goods that were mass produced was very narrow in the early nineteenth century. This would change slowly, as new technologies like sewing machinery and heavy industry based on iron and steel appeared after midcentury. But mechanized manufacturing also would prevail only after improvements in transportation created conditions for specialized production for mass markets. This will be our next theme.

Notes

1 Some further processing might be required to produce final goods. It should be noted that ready-to-wear clothing was a product of the late nineteenth century; in the eighteenth, most clothes were home produced.

2 Not all yarn was woven; some was knit to make hosiery. There, too, machines were dramatically improved in the late eighteenth century. Hosiery played a major role in the career of Arkwright.

3 This is especially the case as improvements proceeded more rapidly on the main roads than on local roads.

4 Modern middle management is a creation of the nineteenth century. Writers in the eighteenth century, including Adam Smith, were sure that one could not trust an agent to do honestly or well any but the most routine and easily checked tasks. Neither pack-horse sales or factory management met these criteria.

5 The classic reference is E. P. Thompson, *The Making of the English Working Class* (New York: Vintage Books, 1963).

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5 Iron, Steam, and Rails

There was much more to the Industrial Revolution than the advance in textile manufacture. Changes in ironmaking and power generation were of equal importance. These also had British origins, but Americans soon adapted them. These innovations would set the stage for momentous changes ranging from the replacement of wood with iron machinery, to steam-driven factories and, probably most importantly, the introduction of the railroad.

In eighteenth-century Britain, coal replaced charcoal as the fuel in the smelting of iron ore. As well, improvements in blowing machinery allowed a tripling of the average size of ironworks over the course of the eighteenth century. The steam engine, invented at the beginning of the eighteenth century, was improved to such an extent that it was applied not only to pumping water in mines and water works but also to replace water wheels as an industrial power source. Ironworks were one of the first industrial operations to utilize the steam engine for it allowed various stages of processing to occur on the same site.

Although American innovators were quick to adopt English advances in textiles, they were sluggish about using coal for ironmaking or employing steam engines. In large part resulting from the abundance of wood in North America, the new ironmaking techniques saw little use until the early nineteenth century. The abundance of water power sites, and the almost complete absence of deep mines, meant that there was at first virtually no place for the steam engine in the United States. As in Britain, American manufacturers would eventually turn to steam power, and would then find it advantageous to locate near raw materials or, more often, the markets of growing commercial centers.

Shortly after 1800, steam engines were developed that were efficient enough to serve the purpose of locomotion. Steam would move both boats and railroad trains. People were no longer limited to the vagaries of wind or animal propulsion to get from one place to another. With its vast landscape and long rivers, the United States proved a fertile ground for the application of these new transport technologies. The scene of innovation thus shifted from England to the United States. In the case of steamboats, most advances first occurred in America. With railroads, the first innovations did occur in Britain, but the requirements of the rugged American landscape soon caused Americans to improve both locomotives and tracks.

These new transport technologies transformed the American landscape. Lawyers and politicians struggled to revise legal codes. Industrialists and inventors strove to take advantage of the emerging national market. Ease of movement gradually reduced differences in culture between regions, and between town and country. The United States would become a different country because of the steamboat and railroad.

A New Iron Age: Coal and the Mass Production of Iron in Eighteenth-Century Britain

In 1700, British iron furnaces were small, with an average output of a mere 300 tons a year, and usually buried deep in the forest due to a reliance on charcoal as a fuel. As noted in Chapter 2, charcoal tends to disintegrate into dust if carried long distances and thus iron works tended to rely on charcoal within a 10 to 15-mile radius. Such ironworks employed a mere handful of workers and were therefore not that different from the cottages that characterized most of industrial production at the time.

The process of smelting ore into pig or cast iron was described in Chapter 2. Although ironmasters of the time could not know this, pig iron was roughly 4 percent carbon, because the iron ore was in contact with the charcoal in the furnace. A small part of furnace output was cast into molds to form pots and pans and furnace grates. The vast bulk of iron output was hammered into shape as agricultural implements, files, cutlery, needles, hammers, or the single greatest use of iron in this wood-reliant society, the humble nail. The high carbon content made pig iron too brittle to be worked. Pig iron was then transported to a forge where it was reheated and hammered so that the carbon was removed to form wrought iron. It was then hammered into the shape of rods for cottage workers who would manufacture the final product.

Steel has a two percent carbon content. Today almost all iron output is transformed to steel (see Chapter 9), for this does not suffer from the brittleness problem of pig iron nor from the inability of carbonless wrought iron to hold an edge. Steel was thus essential for making cutting tools for agriculture, industry, and the home. Steelmaking remained expensive throughout the eighteenth century: It was therefore typical for a thin steel edge to be attached to a tool or implement fashioned of wrought iron.

Some historians have suggested that the English iron industry switched to coal fuel because the price of wood was rising in England as farmland and urbanization encroached on forest. Even more importantly, though, was the drop in the price of coal over this period due to improved transport. Access to broader markets induced many coalmines to install underground railways and achieve economies of scale by expanding their operations. Technological innovation further aided cost-cutting in mining (e.g., explosives, and steam engines for pumping out water and raising coal to the surface) (Figure 5.1).

Experimentation with coal as a fuel began in the seventeenth century. Unknown to the experimenters, coal-smelted pig iron had a high silicon content, preventing the carbon content from being reduced to zero in the forge. It should be no surprise, then, that Abraham Darby, who in 1709 became the first ironmaster to be commercially successful smelting iron ore with coal, was in the business of casting pots and pans. Brittleness was thus not a concern.

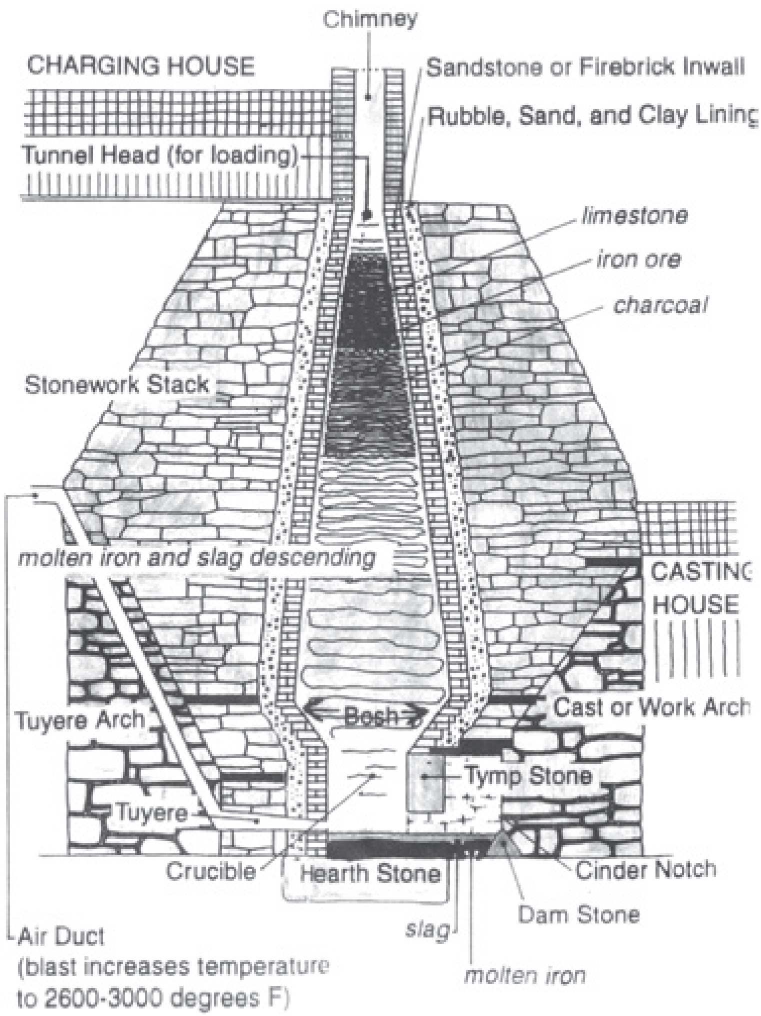

Figure 5.1 A cross-section drawing of a nineteenth-century charcoal iron furnace.

Credit: *Courtesy of The Roland Curtin Foundation.*

Moreover, it was easier to achieve high temperatures with coal than with charcoal. Darby was then able to produce a more homogeneous iron and could cast thinner pieces than had previously been possible.

Historians had long puzzled over why it took several decades for the use of coal to become widespread in English furnaces. The problem was the limited use of cast iron. As the century progressed, a handful of other furnaces came to specialize in casting and relied on coal. Occasionally, excess pig iron from these furnaces was sold to forges; and if mixed in small amounts with charcoal-smelted iron, would produce acceptable wrought iron. Forge-masters, noting the falling prices of both coal and coal-smelted pig iron, naturally turned their attention to technological advances that would allow them to utilize these materials for producing cheaper wrought iron.

The development of new forge technology is a perfect example of how important advances usually involve the actions of countless people over many decades. The use of coal in both furnaces and forge was only possible after a series of improvements occurred. The introduction of a separate refining stage in advance of the traditional fining or decarburizing activity of the forge succeeded in removing impurities such as silicon from the pig iron (although forge masters could not know precisely what it accomplished). Another advance was the reverberatory furnace. Rather than the fuel and the metal being in contact during fining, and thus reacting chemically, the heat would bounce off the walls. The higher temperatures allowed forge masters to produce a more uniform output: This further stimulated advances in the processes by which bars or plates were created.

Henry Cort in 1784 consolidated these and other advances into the 'puddling and rolling' method. To the puddling (melting and stirring) of molten iron in the reverberatory furnace, he added adjustable rollers through which the molten wrought iron was passed back and forth to produce bars and plates of the desired size; as he freely admitted even these were in use elsewhere in English industry. By 1800, the use of charcoal in both furnace and forge was on the way out in Britain.

The use of coal encouraged the increased scale of operation of both furnace and forge—though large-scale charcoal works were established in America in the nineteenth century and Australia in the twentieth century when wood was abundant and coal not close at hand. The increased scale was equally dependent on improved bellows. A constant flow of air into the furnace was necessary to achieve high temperatures. Perhaps because of the higher temperatures attainable with coal, Abraham Darby's descendants replaced leather with wooden bellows in the early 1740s. In 1757, John Wilkinson patented an iron blowing machine. As the century progressed, these devices increasingly were powered by steam engines rather than water wheels. Steam-powered bellows also allowed the consolidation of ironworks whereas furnace and forge would have previously required separate sources of waterpower.

There were few improvements in steelmaking in the eighteenth century. Importantly, steel-makers began to produce steel directly from pig iron (by removing carbon) rather than from wrought iron (by adding carbon) under precise conditions so that precisely the right amount of carbon (2 percent) remained uniformly. The use of coal as a fuel was crucial in rendering the pig iron molten so that the same carbon content was achieved throughout. Steelmakers did not understand the chemical reactions involved. They tried different recipes until they achieved the desired product. They could only produce tiny batches. As a result, steel was still so expensive that it comprised only about 1 to 2 percent of iron production at the end of the eighteenth century.

As the cost of wrought iron fell, a variety of innovations occurred in the trades that used wrought iron as an input. Rolling mills for creating thin metal sheets were introduced late in the seventeenth century and improved steadily after that. One innovation was the use of adjustable rollers. Slitting mills emerged early in the eighteenth century for producing rods the correct size for nailmakers. Wireworks, which provided the same service to domestic needle makers, came a little later. Many metalworking activities became concentrated in centralized workplaces. There, machines were introduced for making nails and for drilling holes in needles. Most importantly, general-purpose stamping and pressing machines were devised and steadily improved. As a result of these various advances, iron machines replaced rickety wooden machinery throughout English industry, opening up entirely new vistas of technical achievement.

Steam Engines: From Mines to Factories

The steam engine symbolizes the Industrial Revolution to many people. It is thus surprising to some that the steam engine was invented decades before the mid-eighteenth century (and before James Watt was even born), yet steam power still provided only a small fraction of the total industrial mechanical energy at the end of the eighteenth century. Nevertheless, just as coal freed ironmasters from the rural sites and limited supplies of charcoal, steam engines allowed all of industry the freedom from reliance on water (or human, animal, or wind) power. As British industry expanded and mechanized in the nineteenth century, it would have faced severe problems in locating additional locales for water-powered factories.

Steam engines were first developed for mines rather than factories. As coal (and tin and copper) production expanded, miners were forced to venture deeper and deeper into the earth. As they did so, they ran into water problems and found themselves unable to drain mine tunnels without a pump. The increased cost of raising coal to the surface provided a further potential outlet for steam power.

In the late seventeenth century, Captain Thomas Savery had developed a steam pump. Called an engine by some, it did not rely on mechanical action. Instead, the condensation of steam was used to create a vacuum that would suck water up a pipe. Then, a blast of steam would blow the water further upwards. The laws of physics limit the operation of such a device to some thirty feet, and so it had limited applicability as mines went deeper. Moreover, the Savery pump was dangerous, and many workers lost their lives as the devices exploded.

Thomas Newcomen followed a more successful path by about 1710. His simple engine followed the scientific principle, known for over a century, that the atmosphere will press upon a vacuum. Newcomen built a large cylinder several feet in circumference containing a piston. Because it was impossible at the time to cause a piston to fit snugly within a cylinder, the piston was packed with watered hemp to create as tight a seal as possible. The cylinder was open to the air at the top but closed at the bottom. The area beneath the piston contained water that would be heated until it turned to steam. This would then be allowed to cool and condense (eventually aided by a jet of cold water), creating a vacuum. The force of the atmosphere above the piston would then push the piston down, creating the power stroke. In a sense, the phrase 'steam engine' is a misnomer, for the Newcomen engine, and the Watt engines that followed, were atmospheric engines—it was the atmosphere that provided the power. Only with Richard Trevithick and Oliver Evans in the nineteenth century would the expansive force of steam itself provide the power for steam engines.

Newcomen engines were designed so that local artisans could build them on site. Brass, copper, lead, and wood were the common early construction materials. In 1725, it became possible to bore iron cylinders; these had the advantage of being able to withstand much higher heat than brass. Over the next decades, many improvements were made in boring devices. The inventive Darbys developed a borer, consisting of a long rod anchored at one end, which could cut a round hole but not one which was very straight: The borer sagged as the rod extended. John Wilkinson developed two new machines in 1774 and 1781 (the first being an offshoot of cannon production). The second machine kept the cylinder stationary while the borer turned, and it was able to achieve much better cylinders.

The fuel inefficiency of the Newcomen engine was not a severe drawback as long as it was used primarily to drain coalmines. Such mines naturally produced a lot of waste coal that was not worth transporting to market. Coalmines would thus stick with Newcomen engines for decades after James Watt developed a better engine. However, the copper and tin mines of Cornwall were far from the nearest coalfield. Urban waterworks were often in a similar situation. Factories were also a potential market for a more efficient engine.

One major source of energy inefficiency in the Newcomen engine was that the cylinder itself had to be alternately heated and cooled to create a vacuum within the cylinder. James Watt's primary contribution was the separate condenser developed in 1776. The idea, again, seems simple. The cylinder and boiler are separate. By opening a valve, steam from the boiler is injected into the cylinder. Opening another valve to the separate condenser created the vacuum. The cylinder itself no longer had to be heated and cooled (Figure 5.2).

Watt's engine would not have been possible decades earlier. For one, he needed steam-proof valves, and the technique for accurately planing these had only recently been developed. Secondly, he required a much tighter fit between piston and cylinder. He relied on Wilkinson's first boring machine and was ecstatic when the second allowed boring accuracy to within the width of a penny. His engine also utilized another advance, the governor, a mechanism that turned down the heat when steam pressure approached dangerous levels. Watt only succeeded because of financing from his partner Matthew Boulton a successful manufacturer of buttons: It took years of expensive experiment, and the employment of skilled artisans, before he achieved success. As the new steam engines gained a market in factories, Watt (and others) developed systems of gears that translated the up-and-down motion of the piston into the circular motion required by machines (Figure 5.3).

The next significant development in steam engine technology occurred at the very start of the nineteenth century. At that point, Richard Trevithick in England and Oliver Evans in the United States simultaneously developed engines in which steam provided the power stroke. The high pressures involved naturally required even stricter engineering standards than those available to Watt. Among other things, the Trevithick/Evans engines had a much higher

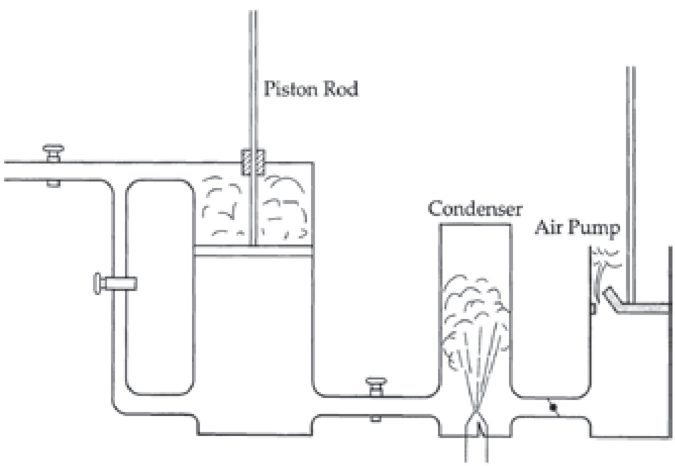

Figure 5.2 A schematic drawing of the Watt steam engine. The condenser was kept cold. Thus, when the valve between it and the cylinder was opened, the steam from the cylinder would condense in the cold, and a good vacuum would remain in both.

Credit: *Adapted with the author's permission from DSL Carwell,* Technology, Science, and History, *London, 1972, 87.*

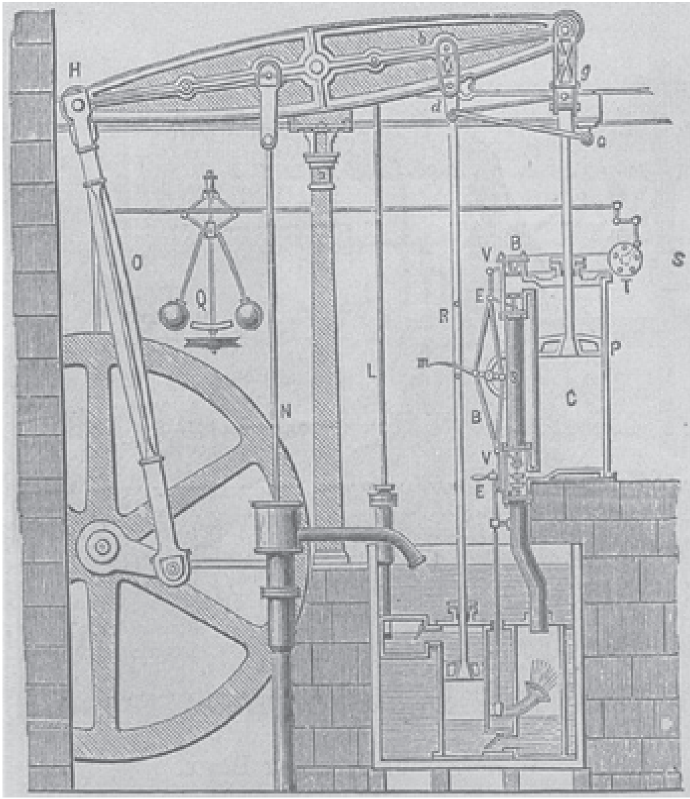

Figure 5.3 Watt's steam engine. Notice the beam, crank, and cylinder.
Credit: Popular Science*, December 1877, 140.*

power to weight ratio (i.e., an engine of a given weight could produce much more power) than could ever have been achieved by atmospheric engines. This fact made possible the portable power required for railroads and steamships.

Technology Transfer?

At the time of the American Revolution, the American iron industry, although based on small charcoal furnaces, supplied not only the domestic market but exported both pig and bar iron to Britain. Soon after that the technical advances in British furnaces and forges so decreased the price and increased the quality of British iron that American producers not only lost this export market but also found themselves competing with imported British iron. Although usually quick to adapt European technology, the United States was very slow to utilize the new British iron-making technology. Technology transfer has two components: The actual movement of knowledge from one country to another, and successful adoption in the latter. As seen in the preceding chapter, knowledge moved readily from Britain to the United States. Why was the new technology not adopted? One obvious explanation is that the United States at the time had access to almost unlimited forest resources. Existing furnaces were located where charcoal was readily accessible, and in the face of cheap imports, there was a limited incentive to establish new ironworks. Early in the nineteenth century, the situation became more favorable in many ways. The vast bituminous coal fields near Pittsburgh were opened up, allowing adaptation of new English ironmaking techniques. At that time, some English workers familiar with coke furnaces or puddling and rolling immigrated to the United States and, in concert with American entrepreneurs, supervised the adaptation of this technology to American resources. The imposition of tariffs against imports may also have encouraged investment in American ironworks embodying the new technology. From about 1815, the new techniques steadily gained an increasing role in the American iron industry (although charcoal furnaces would survive for decades). Nevertheless, the most substantial American ironworks remained much smaller than European counterparts until very late in the nineteenth century, in part because of limitations in transport infrastructure and in part because of continued reliance on both wood and water power.

The Newcomen steam engine had an even slower start in the United States than did puddling and rolling. Four decades elapsed between Newcomen's invention and Philip Schuyler's decision to use a Newcomen engine to drain his New Jersey copper mine in 1753. He not only imported the engine but numerous spare parts and Josiah Hornblower, a member of one of England's most important steam-engine-building families, to install and maintain it. However, this was the only role for a steam engine to play in eighteenth-century America. The colonies had an abundance of waterpower. Coal was only beginning to be used in the United States and could thus be obtained close to the surface; drainage of coalmines was not necessary. Schuyler's was the only copper mine with drainage problems. The large-scale industrial establishments that wanted more regular power than water alone could provide would not appear until the nineteenth century. Thus, Schuyler's engine had no imitators.

The Watt steam engine fared only somewhat better when it was developed later in the century. In the mid-nineteenth century the steam engine would make possible large industrial cities, powering not just factories but streetcars, and heating office buildings, but in the eighteenth-century American industry maintained its more picturesque rural setting. One crucial development early in the nineteenth century involved rendering the Lehigh River navigable; a gravity railroad with speeds of 30 miles per hour moved coal from the Summit Mine to the river and on to Philadelphia and later by rail to New York: The gravity railroad became a tourist attraction, effectively serving as a rollercoaster. Access to inexpensive coal encouraged the use of steam engines in urban factories.

The most significant interest, though, lay in the possibility of steam-powered transport. Here was an area in which the United States offered a potentially massive market for the steam engine. The American John Fitch in 1785 designed a steamboat powered by the Newcomen engine. However, the heavy, inefficient Newcomen engine was not at all suited to locomotion; Fitch and others thus turned their attention to the Watt engine. Although much better, this also had too low a power-to-weight ratio for transport. This fact encouraged the development of high-pressure engines.

Transport links between and within the colonies of the Atlantic seaboard were, as we have seen, very poor, and this condition continued for decades after independence. As we saw in Chapter 2, however, improvements in overland transport took place in the generation before the age of steamboats and railroads. State legislatures established turnpike and river improvement companies from the 1790s. Pennsylvania subsidized some turnpikes, but most states relied on private finance entirely, as Britain had done. Private companies, with the right of eminent domain, had soon built a system of all-weather roads along much of the eastern seaboard. From the 1810s, attention turned to canals, which were often subsidized by state governments because of their high cost; but they often opened up vast new areas to settlement and increased the activity of port cities and manufacturing centers. New York State's Erie Canal (opened in 1825), which provided a cheap connection between the Great Lakes and the Atlantic via a canal linking Buffalo on Lake Erie with Albany on the Hudson River, guaranteed the ascendancy of New York City as the country's premier port. Still, many states that tried to emulate New York's success incurred massive debts only to build canals with little commercial value. The Appalachians proved a more formidable barrier than the Pennsylvania government had realized, and its canal never carried but a fraction of the traffic on the Erie. Railroads would later provide a much better means of traversing mountains.

Although the canal mania ruined some state finances, the result of these activities was that the populous parts of the United States had a good road network and water linked the primary agricultural and industrial areas and markets on the eve of the railroad era. After the arrival of the railroad, the roads and waterways would continue to be expanded and play a vital role in American transport. Even though the steamboat and the railroad would be great advances, especially in terms of opening up the west, the process of linking together the dispersed American population was already underway.

The Steamboat

In both North America and Europe, experimentation with steamboats began in the late eighteenth century. The almost simultaneous development of the high-pressure engine by Richard Trevithick in England and Oliver Evans in the United States in 1804 at last gave steamboat designers a suitable engine.

The United States is blessed with an extensive network of rivers. Many of these have lengthy stretches unobstructed by rapids. The construction of locks and the addition of linking canals added considerably to this network. It is thus no surprise that the first commercially successful steamboat operation was in the United States (Figure 5.4).

The Mississippi system was the great instigator of steamboat schemes: If ships could move upstream on the Mississippi and its tributaries the interior of the continent could be opened to commerce. Before steam, boats were painstakingly poled upward on the Mississippi: Workers would push a pole into the muddy seabed and walk from front to rear of the boat (oars, sails, and pulling from shore were tried, but all proved problematic). Commerce in the American interior was severely limited while upstream travel was so difficult. The Hudson River and the Chesapeake Bay region were two of the areas along the eastern seaboard that also provided a great opportunity for steamboat technology.

Success with steamboats in the nineteenth century was only possible because of numerous failed experiments in the eighteenth century. John Fitch launched the Perseverance in 1790 after years of trying to gather both the necessary financial backing and technical expertise. Fitch's first boats were operated by paddles suspended over the side of the vessel and moved back and forth by the piston; he later used paddles suspended from the rear of the boat. Although Fitch designed a model with an endless chain of paddles, he never put this

Figure 5.4 The Harriott, a nineteenth century steamboat in Montgomery, Alabama.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

forerunner of the paddlewheel into practice. Although his ships were based on the Watt engine, he and his associates made numerous improvements, especially to the boilers.

Another early American steamboat experimenter was James Rumsey. Acting on the advice of no less than Benjamin Franklin, he built boats in which jets of water expelled from the rear of the boat provided the propulsion. He contributed an important advance in coupling the steam engine piston to the water turbine, which discharged water from the vessel: This would be a standard feature of steamboats in the second half of the nineteenth century. In 1804, John Stevens launched a boat driven by one of the 'modern' methods of propulsion, the screw propeller. Hindered by shoddy construction, this craft achieved little success.

Robert Fulton was the one who would first develop and operate a successful American steamboat (William Symington briefly ran the world's first commercial steamboat, the *Charlotte Dundas*, near Glasgow, Scotland, in 1802)). The son of Irish immigrants to Pennsylvania, he became acquainted with steamboat technology during visits to Europe in pursuit of a career as an artist. His artistic talents proved insufficient to support him comfortably, his plans to revolutionize canal design and to introduce submarine warfare had no impact, and his efforts at improved bridge design had only slightly more success. Then, in 1801 while in Paris, he met Robert Livingston, who possessed a 20-year monopoly for steam navigation in the state of New York. In 1803 in France, with Livingston's financial help, Fulton built a six-horsepower steamboat that relied on one side-mounted paddle wheel. Although this boat proved troublesome, he ordered a much larger 24-horsepower Watt engine, and numerous other components, to be delivered to New York for his return in 1806. By late 1807, he had constructed a 146-foot long steamboat with a paddle wheel on each side. The boat used the abundant local supplies of wood for fuel rather than expensive coal. It proved highly dependable and was able to make the trip between New York and Albany in 32 hours, whereas sailing vessels took four days or more: The Hudson was notoriously tricky for sailboats to navigate. His steamboat immediately became highly profitable.

Fulton then turned his attention to the vast interior of the continent. He designed and had constructed in Pittsburgh a steamboat that steamed successfully downriver to New Orleans in 1811–1812. Because Livingston and Fulton had also gained a steamboat monopoly for the New Orleans territory (present-day Louisiana), this boat also proved a tremendous commercial success and was the forerunner of an entire fleet of Mississippi steamboats.

Although Fulton died suddenly in 1815, he had accomplished much by then. He had established the utility of steamboats on both the Mississippi and the eastern seaboard, as well as for cross-river ferries in New York, Boston, and other centers. He had supervised many improvements, including modifying the engine, strengthening the hull, and covering the paddle wheels (in part to fend off 'accidental' attacks from jealous sailing ship masters). Fulton is sometimes criticized for not having really done anything 'new.' His case is much like that of Henry Cort. Just as Cort was the first to recognize the potential of rollers for creating homogenous iron rods and plates, Fulton was the first to see the future of the paddle wheel. Like Cort, he brought together many existing ideas and proved that the steamboat was economically viable.

Steamboats were steadily improved, especially as more firms entered the industry as Fulton's monopolies were challenged. By the 1850s, speeds of twenty miles per hour were common. Higher and higher pressures were achieved in the steam engines as the century progressed, especially in the West, where the ability of high-pressure engines to utilize muddy river water was highly valued. Explosions remained all too common until Congress imposed stringent standards on engine construction in 1852. In the West, boats were redesigned to have a minimal draught under 3 feet to overcome the problems of navigating shallow tree-strewn rivers. Of all western steamboats built before 1850, 30 percent were lost in accidents, most often from hitting submerged tree trunks.

Early steamboats often frightened with their noise. Explosions and accidents frequently occurred in the early decades of steamboats. Yet the economic importance of steamboats was such that governments regulated rather than banned them.

By midcentury, iron-hulled ships became common. From the 1840s, the falling relative price of coal and improved methods of burning anthracite caused coal to replace wood as fuel. Especially in the East, where passenger transport was the primary occupation of steamboats, interior decorations were enhanced until the boats became known as floating palaces. The crews on paddleboats were ethnically stratified, with slaves, ex-slaves, or immigrants performing the dirtiest and most dangerous work. Late in the century, the propeller replaced the paddle wheel on all but the shallowest rivers. The propeller had long been favored for ocean traffic because in rough seas the paddle wheel was often out of contact with the water. Its late adoption on American rivers may partly explain why Americans, despite their lead in river steamboats, played a minor role in ocean steamships in the nineteenth century.

The period 1815–1860 can be considered the golden age of steamboats. By 1830, they dominated river transport, especially in the West. Seventeen steamboats with a combined capacity of 3,290 tons operated in the Mississippi system in 1817. By 1820 the numbers were 69 and 13,890, and by 1855 there were 727 boats with a combined tonnage exceeding 170,000 tons. Since steamships were becoming faster over this period, these figures underestimate the increase in steam capacity. From 1830 to 1850, steamboats were the most important mode of transport in the country. By 1860, steamboats were plying minor tributaries of the Ohio and reached 2,200 miles up the Missouri to Fort Benton, Montana. They were able to link vast regions of the country together as never before. Gradually, they were displaced by the railroad, but they remained a valuable form of transport into the next century (Figure 5.5).

Figure 5.5 (Map 5.1) American Canal and Riverboat System.

Railroads

John Fitch, one of the early experimenters with the steamboat, turned his attention to boats only after recognizing the much greater problems inherent in any type of steam carriage. Travel over the smooth surface of the water was much easier to power. The uneven terrain and vast distances of the United States posed special engineering problems for overland transport. Locomotives were necessarily limited in size relative to steamboats and thus required compact but powerful engines. The railroad, therefore, arrived on the scene after the steamboat. But it was to have much more far-reaching consequences. While the steamboat was limited to navigable rivers and estuaries, the railroad could potentially go everywhere (Figure 5.6).

Americans would follow the British lead in railroads. Britain possessed a flatter terrain, denser population, and greater technical and financial resources. Because a successful railroad required much more than just the construction of a locomotive, the financial and technical requirements were much greater than for steamboats. As Britain had already completed her canal network, it was natural that promoters would turn their attention to this new mode of transport. Moreover, British coal mines had long used horse-drawn underground railways, and this coupled with British expertise in steam engines provided a firm basis for railroad development.

Although the first locomotive was built in 1803 by Richard Trevithick, the first railroad, the Stockton and Darlington, did not open (in northern England) until 1825. In the interim, steam engines and boilers were much improved.

Figure 5.6 A train from the 1830s. Notice the adaptation of the horse-drawn carriages.
Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

So was the track. Richard Trevithick had directed his talents elsewhere after the derailing of his third locomotive in 1810, caused by the flimsy track of the period. The Liverpool and Manchester Railway organized trials in 1829 to choose their locomotive. Robert Stephenson's 'Rocket' won handily, The 'Rocket' had a multitubular boiler and direct gearless drive that would be the basis for future generations of locomotives. The railroad's promoters were pleasantly surprised by the traffic, especially of passengers, that it attracted; and others soon followed it. By 1841, there were over 1,300 miles of railroad in England and Parliament authorized 400 new lines between 1844 and 1846.

The United States, with its vast territory, was among the first nations to follow the British lead. There had been considerable interest even before the Stockton and Darlington. In 1812, John Stevens had published a popular pamphlet advocating the superiority of railroads over canals. He obtained a New Jersey charter for a railroad between New York City and Philadelphia, but he could not proceed given the technology of the time. He did build the first steam locomotive to run in the United States on a half mile circular track at his home in Hoboken, New Jersey in 1825.In 1830, the Baltimore and Ohio company opened the first 13 miles of its line (which would reach the Ohio River in 1852, and expand far beyond), and thus became the first commercial railroad on this continent (the first Canadian railway opened five years later). Other lines quickly followed; by 1840 there were 2,800 miles of track and by 1860 over 30,000.

By 1840, in fact, there was twice the length of railroad in the United States as in Europe, partly because of the need for a new mode of transport to tie together the American landmass. The process was also aided by the lack of national boundaries to be crossed and the much lower price of land.

It is estimated that British railroads spent more just on land before 1868 than American railroads spent on land plus construction to that date (Figure 5.7).

The B&O and other early American railroads relied on locally built locomotives. The limits of these were shown when the 'Tom Thumb' lost a race with a horse. Although American engines were adequate, British engines were, at this point, superior. The first British locomotives were imported to America in 1829. Between 1829 and 1830, the New Jersey legislature granted a monopoly to the Camden and Amboy Railroad Company for the most important route in the country, that between New York and Philadelphia. The proprietors bought a locomotive from Stephenson which they named the 'John Bull'. It took the railroad's skilled mechanics ten days to reassemble the locomotive in New Jersey—hey had never seen a locomotive before. After an investment of over $3 million (each locomotive cost $124,000), a prodigious sum for the time, the railroad was opened by sections between 1832 and 1833. The railroad proved an instant financial success, and other railroads looked to the 'John Bull' for inspiration. Over the next decade or so, another 120 locomotives were ordered from England.

American railroads changed British methods of laying track. British rails were laid on parallel lines of stones. In the United States, it was soon discovered that winter frosts threw these stones out of alignment. After considerable experiment, the now-familiar system was adopted—wooden ties laid upon a gravel roadbed from which water drained readily. The rails themselves also changed: Iron strips had previously been attached to wooden rails, but these often peeled off and were driven into coaches at great risk to the passengers. T-shaped iron rails were accepted by the mid-1830s. The hilly terrain and shortage of capital also caused American railroads to allow steeper inclines and sharper turns than was considered good practice in Britain.

Once track design came to differ in the two countries, it was only natural that locomotive design would also begin to diverge. By 1840 there were ten specialist locomotive manufacturers in the country. One of these, the Norris Locomotive Works in Philadelphia, employed 650 men to make 65 locomotives in 1831. American engines were built larger and more powerful than British engines so they could handle steeper grades. They also incorporated the bogie truck, four lead wheels which could swivel independently, an English invention first put to use in the United States to prevent trains from derailing on curved tracks. Other American adaptations included the cowcatcher on the front, needed because American railroads were not fenced off, and large smokestacks to combat the potential of wood fuel for causing fires along the route. Although only 35 locomotives were built in the United States in 1835, the number was 200 in 1845 and 500 in 1855; as early as the 1840s Americans were both exporting locomotives to Europe and designing railroads overseas.

In the second half of the nineteenth century, railroads steadily increased their dominance of national transport. As we would expect, numerous technical

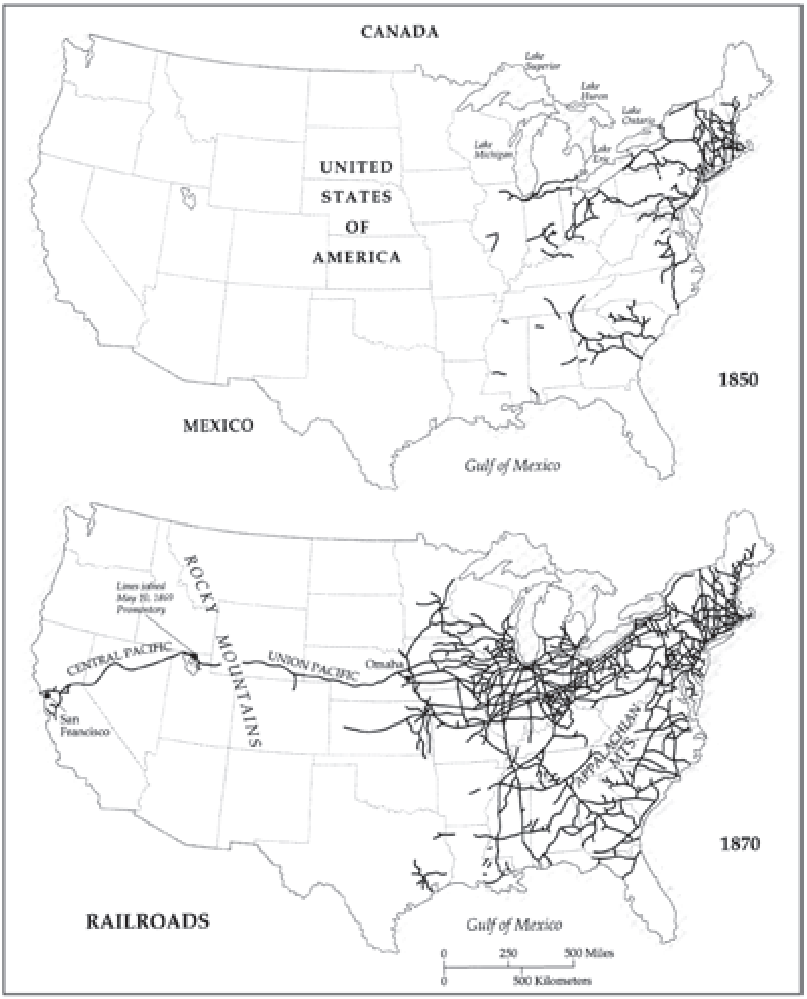

Figure 5.7 (Map 5.2) Growth of the American railroad system, 1850–1870.

innovations encouraged railroad expansion. Safety was one critical area, for as traffic had expanded and speeds increased—30 miles per hour was not uncommon in 1860—on the early (generally single track) railroads accidents had become much too familiar. One author in the 1860s remarked:

> Every day the record of mortality is increased. Now it is a collision; now the explosion of a locomotive, and then again the sudden precipitation of an entire train down a steep embankment or perhaps into some river .... Every man or woman who steps out of a railway car unhurt does so with a feeling of sensible relief.[1]

A manual signal system to tell trains that there was another train on the next section of track had been introduced in the 1830s and became common in the 1840s, but there was still considerable scope for human error until the automatic electronic signal of 1872. Other responses included air brakes and the use of the telegraph for train dispatch. As a result, although locomotives became much bigger and faster, the accident rate fell in the latter decades of the century.

Wooden truss bridges were developed in America for roads in the early nineteenth century, and where iron was expensive, especially in the West, wood would continue to be used thrwoughout the century. The first steel bridge was built over the Mississippi at St. Louis between 1867–1873. John Roebling pioneered the suspension bridge at Niagara in the 1850s and between New York and Brooklyn a decade later. The tunnel shield, which prevented tunnels under construction from flooding, was developed in Britain but Americans soon adopted this tunneling technique as well.

Railroads were not merely a technical accomplishment. They were the largest firms of the era in both Britain and the United States. These large organizations needed tight coordination in order to keep to a schedule and avoid accidents. As with technological innovation itself, the efficiency of managerial hierarchies was improved through time by numerous small improvements. Before the railroad, the position of middle manager—a person who supervised managers and reported to yet other managers—was largely non-existent (the military provided some insight on how to run a large organization, and there was some movement on senior officers into railroad administration). The railroads trained such managers and developed the mechanisms for career process through a corporate managerial hierarchy that would become ubiquitous in American industry in the twentieth century.[2] Many railroad managers—most notably the steelmaker Andrew Carnegie—moved from railroads to develop similar organizational structures in other sectors. These new managerial hierarchies—precisely because ownership became separated from management—in turn gave permanence to corporations that had previously been rare in family firms.

Governments played an important role in determining the number, size, and shape of railroad companies, and the timing and extent of railroad construction. Since railroads provide benefits to the economy far in excess of the profits earned by the railroads themselves, governments from the beginning had subsidized railroad projects just as they had previously done with canals. Although considerable waste and corruption occurred, such government support was often essential to the construction of valuable railroad lines. One key innovation was to give railroads land grants along their routes. This approach was first used as railroads opened up the Midwest. Then the federal government granted over 130 million acres for 18,000 miles of rail line as transcontinental railroads were built from the 1860s. Although railroads often abused their land monopoly, these grants had important advantages: They did not cost financially strapped governments anything up front, and they gave the railroads an additional incentive to open up new territory so that the value of their land would appreciate.

Technology and the Law: The Wheeling Bridge Case

Legal systems evolve to reflect changes and conflicts in society. American legal historians usually argue that the American legal system was unusually flexible and tended to favor the forces of technological change over entrenched interests. This would undoubtedly be the case in comparison to many, if not all, European nations. Still, American innovators often had to battle in the courts to achieve their purposes. Vested interests sometimes use legal avenues to halt technological change that they deem threatening. Thus, the law could affect the course of innovation.

A good example is the case of the Wheeling Bridge company, which in the middle years of the nineteenth century proposed to build the first bridge across the Ohio River. Although not affiliated with any railroad, steamboat interests from Pittsburgh viewed this bridge as a harbinger of the railroad, especially as the Baltimore and Ohio Company expressed interest in crossing the river once it had expanded that far. Steamboat companies complained that the bridge would block their movement along the river. They were also clearly worried about competition from the railroad. When the steamboat companies launched a lengthy court battle to prevent the bridge's construction, the government of Pennsylvania supported them, in large part to protect its investment in the trans-Pennsylvania canal. The government of Virginia supported the bridge company in turn.

The court battle was not a clear-cut confrontation between new and old (with steamboats, in any case, not being all that old themselves). The Pittsburgh interests spoke of the longstanding principle of freedom of navigation, and particular passages in the Northwest Ordinance that guaranteed that freedom on the Ohio River. Bridge proponents noted that the ordinance had also promised a road link to the Ohio region. As the battle heated, and as Congress was drawn into the fray, the case also involved the different views of northern and southern states about states' rights versus national power and differing opinions of the relative strength of Congress and the Supreme Court.

Technical issues were central to the case. As first proposed, the bridge would have obstructed only the very tallest of steamboat chimneys, and then just when the river was at its highest. Steamboats were being designed with taller and taller chimneys over this period, however, and thus with each passing year the proposed bridge become more of a threat. The litigants thus debated whether taller chimneys enhanced engine efficiency as much as was believed. They also discussed the cost of hinged chimneys, which could be lowered to pass the bridge, as was done on the Louisville Canal. Then they tackled the economic importance of the steamboat traffic above Wheeling (discussing how navigable the Ohio was) and how dependent this traffic was on tall chimneys.

The Supreme Court eventually compromised. The right to navigate was not absolute; some obstruction would be allowed. The bridge company had to amend its plans to minimize obstruction but was allowed to build. The Court decided that it was up to Congress to determine the precise compromise. The Wheeling Bridge Case thus established the legal framework that permitted railroads over the next decades to bridge the major rivers of the nation. At the same time, legal restrictions encouraged improvements in bridge design. In turn, as bridge technology improved, legal restrictions became correspondingly more stringent (Figure 5.8).

Economic Impact of Steam Transportation

There can be no doubt that both the steamboat and railroad revolutionized American transport. Entire regions that would hardly have been touched, especially in the West, were opened up to settlement and exploitation. In a geographic sense, their impact was immense. Some historians have argued further that they were the key to the rapid economic growth experienced by the United States in the middle decades of the nineteenth century. The railroad especially not only lowered transport costs but caused a surge in the output of the iron, coal, and engineering sectors. Thus, it was a driving force in economic development.

Figure 5.8 Wheeling Bridge from westshore.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

In recent decades economic historians have attempted to quantify the economic impact of railroads (much less research has been done on steamboats, not to mention turnpikes or canals).Both Robert Fogel and Albert Fishlow found that, assuming appropriate investments in canals and roads would have occurred, the total of railroad services for a typical year in the late nineteenth century could have been provided by other means at a cost of less than 5 percent of national output (that is, at the cost of just a couple of years' worth of economic growth).Moreover, the effect of railroads on the iron and coal industries had been greatly exaggerated.

Still, Fogel recognized that he could not measure the *dynamic* effects that railroads might have had. By tying markets together, they allowed firms to operate at a much larger scale than previously. By facilitating personal travel, they increased the flow of ideas and likely had a significant impact on the rate of innovation, because technological innovation involves the synthesis of diverse ideas. The fact that firms were exposed to a broader range of raw materials, and new marketing opportunities, must also have spurred innovative activity.

The railroad also accelerated a decline in travel times that had been happening for decades with improved roads, stagecoaches, canals, and steamboats. In 1790, it took one week to reach Maine from New York and two weeks to reach Florida; and no stagecoaches crossed the Appalachians (intrepid travelers would spend at least five weeks reaching the present site of Chicago).By 1860, a New Yorker could reach Maine in a day, and Florida in three; most dramatic was the fact that by rail Chicago was now only two days away. In the next decades, transcontinental railroads would tie the Far West to the rest of the country. Although automobiles and airplanes would further reduce travel times in the next century, the impact of the railroad was arguably more profound. Many previously isolated regions were now enveloped in the national economy.

The social effects went beyond the strictly economic. Travel for pleasure became a possibility for many, given the high speed and low cost of railroad travel. With the freedom to travel came a greater sense of national identity and a reduction in regional cultural diversity. Farm children could more easily acquaint themselves with the big city, and easterners could readily visit the West. It is hard to imagine a United States of continental proportions without the railroad. Arguably, because of its speed, the railroad also changed the way that Americans viewed nature: As a distant panorama rather than immediate experience.

The economic impact on local economies could be huge. Many towns began as division points where train crews changed and locomotives were watered. Others became industrial centers because the railroad linked them to materials and markets. On the other hand, those towns and regions without access by rail to coal suffered competitively in the age of steam. Farmers who would otherwise have been limited to a local market were able to specialize in crops best suited to their soil and climate.

Finally, the railroad had major impacts on how goods were distributed: First wholesalers in the 1850s and then department stores, chain stores, and mail-order companies from the 1870s created large national markets for products. As had happened with changes in distribution ushered in by improvements to roads in the eighteenth century, these developments changed the way producers operated. In the latter decades of the nineteenth century, companies such as Heinz, Borden, Campbell's Soup, Libby's canned meats, and Eastman Kodak created large hierarchical organizations to manage both large-scale production and national marketing of their goods. The revolution that began in England at the beginning of the eighteenth century with improved ironmaking and Newcomen's steam engine culminated in the next century with the steamboat and railroad that touched the lives of all Americans.

Notes

1 In *Harper's Weekly*, 1865, cited in Brooke Hindle and Steven Lubar, *Engines of Change: The American Industrial Revolution 1790–1860*, 149.

2 Cultural attitudes also had to change. Magazines hailed the adventure and challenge of middle management, seeking to establish that this was a suitably 'manly' line of work.

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6 Machines and Their Mass Production

We have already seen the great effects of industrial technology on nineteenth-century American society. The cottage spinning wheels were replaced with the water frame, wooden machines with iron ones, and canoes and horse-driven wagons with paddle steamers and railways. Another complex process was emerging about the same time: The mass production of machines. In many ways, this was the most difficult challenge of early industrialization. It was one thing to turn out thousands of yards of cotton cloth; it was quite another to fashion and assemble complex parts into machines like reapers, guns, or clocks. The difference encompassed not only the need to manufacture a number of specialized gears, cranks, and other components, but also to fit them together into a working product. The two problems were closely related: Handicraft methods did not produce parts that could be assembled without expensive filing and fitting. Parts were not interchangeable: When a machine like a gun was assembled, its parts fit together with only that one product and required costly fitting of new parts during repairs. While this assured constant work for local blacksmiths, few consumers could enjoy labor-saving machines because of their great expense. Indeed, these conditions of manufacture made inconceivable the mass ownership of sewing machines, typewriters, and other home appliances, much less automobiles. Handicraft methods made difficult the equipping of mass armies with millions of weapons. Cheap machines required new methods for manufacturing components that were exact copies allowing assembling with little or no filing and fitting costs; only such parts could be successfully interchanged in assembly or repair. This meant the replacement of handicraft methods with accurate measuring devices and especially machine tools that could fabricate thousands of parts that were exactly the same. This technology was associated with the term, the American System of Manufacturing.

The advantage of making identical parts that could be interchanged was understood fairly early. In 1798, Eli Whitney won a receptive audience in the US government when he promised that he could produce ten thousand muskets in two years. Whitney assured government officials that he had mastered the technology of manufacturing interchangeable parts. In fact, he was very far from actually being able to deliver. It took him ten years to fill that order, and then his goods were of poor quality Even so, partly as the result of Whitney's publicity, interchangeability became a powerful idea that eventually led to the mass production of machines and the American System of Manufacturing.

From File to Milling Machine: Origins of Mechanical Tools in Industry

Whitney's failure was mostly due to his lack of machine tools that could produce uniform components. Whitney relied upon handmade parts, sometimes milled or drilled with the aid of jigs (devices that fixed workpieces for precise drilling or cutting). He used gauges and master models for measurement to assure that a series of parts remained uniform. Still, only after painstaking filing could pieces of Whitney's gun locks be fitted together.

Interchangeability required a shop full of machine tools that not only sped up the work of hand tools like chisels and hammers but produced uniform results. Many of these machine tools were of English origins (especially from the clock industry). For example, the slide rest of the modern lathe allowed a precise and uniform cut to be made into and across a revolving workpiece essential for close-fitting parts of clocks (Figure 6.1).

The firearms industry provided a particularly important route to the modern machine shop. At least from 1640, Italian cannon works used a water-powered boring-mill, a round cutting tool on a long pole that drilled out the cores of cast metal cannon, ensuring a relatively uniform thickness. In 1774, an English ironmaster, John Wilkinson, built a boring mill that rotated a large piece of cast iron in the shape of a cannon against a fixed cutting head that was advanced by a toothed rack, creating a relatively uniform core, essential for accurate firing of a cannonball. Wilkinson's boring machines were essential in the manufacture of cylinders for Watt's first steam engines in 1776 (see Chapter 5).

The connection between arms making, steam engines, and machine tools was obvious in the career of the Briton Henry Maudslay (1771–1831). Apprenticed at the English state arsenal in 1783, he soon became a master machine builder. Around 1800, Maudslay invented an automatic lathe, which combined a slide-rest tool fixture with a lead screw that automatically advanced the cutting tool across the piece turning in the lathe. This machine was adapted to the making of screws, allowing for standardized screw threads—essential to the repair and assembly of machines. Improved taps for threading holes in metal helped solve innumerable problems in machine making. Maudslay's youngest disciple, James Nasmyth (1808–1890), invented a steam-driven hammer that greatly eased large-scale forging (shaping hot metal objects). Although none of these inventions may be exciting, they were essential to the long journey toward the mass production of mechanical goods.

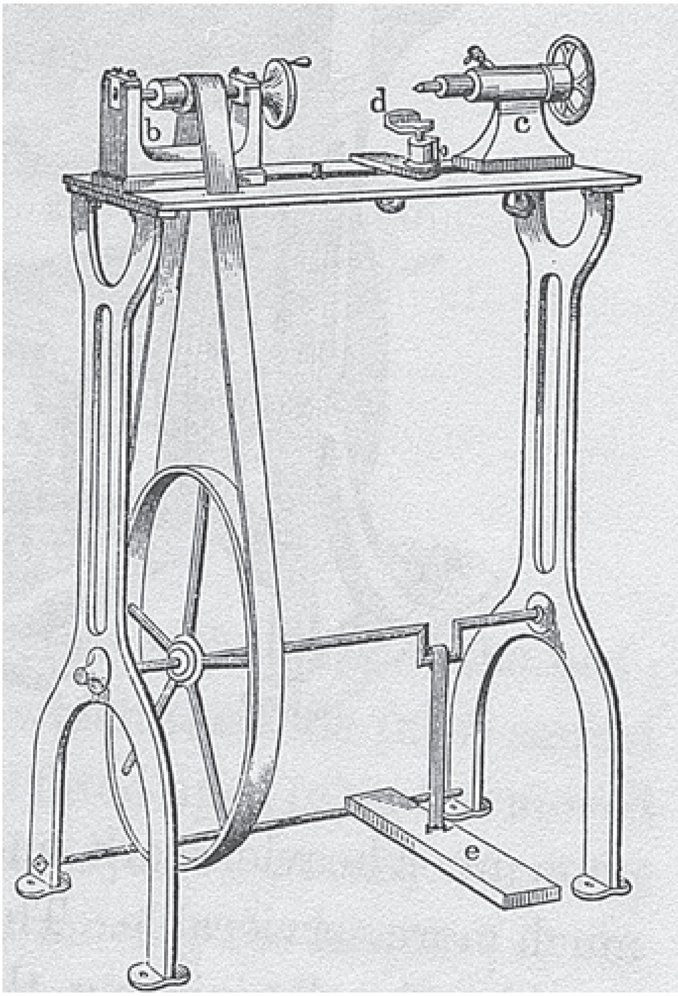

Figure 6.1 This simple lathe spins a piece of metal or wood by the movement of a foot petal while a tool on 'd' cuts against it to shape or groove it.

Credit: *W. Henry Northcott,* A Treatise on Lathes and Turning*, 1868.*

Armories, Interchangeable Parts, and the Origins of the American System of Manufacturing

American government-run arms factories (armories) introduced many of the machines that led to the mass production of assembled consumer goods. Many people today find this surprising because they assume that only the profit motive of free enterprise provided the incentive for such innovations. Indeed, the American patent system, which granted exclusive property rights for authentic inventions for fourteen years (today twenty years from filing), encouraged an entrepreneurial approach to innovation. However, as is true today, early private entrepreneurs were unwilling or unable to invest in costly innovations such as special-purpose machinery, especially to *mass* manufacture goods for which there were no certain buyers. Manufacturers of a plow, gun, or even table knife could not be sure that they could make a profit if they invested in these machine tools. Costs and limits of transporting such goods further limited the incentive to pour money into machinery to mass produce goods. Regional and social distinctions as well as differences in personal taste required custom-built furniture and even weapons.

In these respects, the manufacture of military weaponry in government-run factories had a distinct advantage over private producers. State armories were less hampered by the need for immediate return on investment, and mass-produced weapons had an assured market in the US Army. In any case, Americans, before the Civil War especially, expected government to provide leadership in innovation: The military surveyed and built roads, and state governments subsidized railroad and canal construction until private enterprise could be guaranteed a profit. Similarly, government 'armory practice' in production methods spearheaded what would become the American System of Manufacturing that was applied to a vast array of mass- produced goods.

Following the War of 1812, government officials complained that arms suppliers had failed to deliver enough quality weapons. In an effort to obtain a reliable and uniform supply of arms, Washington directed the two government-owned armories, located in Springfield, Connecticut, and Harpers Ferry, Virginia, to produce firearms that were interchangeable with each other. By 1821, a 'pattern musket' was manufactured at both armories. Based on models (or patterns) against which components were shaped, cut, drilled, and milled, this musket met a minimal standard of interchangeability. In 1826, aided by an elaborate array of gauges and specialized equipment, John Hall manufactured mostly interchangeable rifles at Harpers Ferry. It was only in the 1840s, though, that the Model 1841 percussion rifle was mass produced economically with interchangeable parts.

Interchangeability was not clearly an economic advantage at first: John Hall's nearly interchangeable rifle in the 1820s simply was too costly per unit, given the low demand for his product, to compete against rifles made in more traditional ways. Only government subsidies allowed their construction. Still, these early efforts at interchangeability created the specialized machine tools required for modern mass production.

In 1818, Thomas Blanchard (1788–1864) installed his ingenious pattern lathe at the Springfield Armory. This machine could cut an irregular wooden shape from a model. This machine overcame an old bottleneck in musket production, the making and fitting of the gun stock. John Hall's massive drop presses operated on a simple but effective principle, dropping heavy weights on soft metal pieces that were pressed into the shape of a die (a metal model) underneath. This process saved much hand forging, and assured far greater uniformity and, thus, interchangeability. Hall also devised numerous special-purpose machines to drill, cut, and grind components of firing mechanisms (locks) (Figure 6.2).

The private arms industry that formed around Springfield also produced innovation. Stephen Fitch, in 1845, built a lathe that accommodated a number of tools mounted on a 'turret.' In 1873, the turret lathe was automated by a famous maker of the repeating rifle, Christopher Spencer (1833–1922). His 'brain wheel' mechanically switched from one tool to another on the turret, thus greatly easing the cutting of complex parts.

Milling machines were also important. These disc-shaped cutting tools rotated against a fixed workpiece advanced by a cross slide rest. Among other purposes, the milling machine replaced hand filing and chiseling required in the making of gun locks, again producing much more uniform and interchangeable pieces. This machine appeared first in a small Connecticut arms factory in 1818, but it was greatly advanced in 1850 when Frederick Howe (1822–1891) invented a milling machine that could feed the workpiece both vertically and horizontally.

Along with new machinery came increased specialization of jobs (subdividing many tasks that had been done by skilled artisans). This change allowed management to hire less-skilled (and often cheaper) labor and to increase managerial control over the production process. In sum, the result was the American System of Manufacturing.

From Guns to Typewriters: Mass Production of Complex Products in the Nineteenth Century

To the amazement of Europeans, American manufacturers created a sensation at the Crystal Palace industrial exhibition held in London in 1851. Alfred Hobbs's padlocks, Samuel Colt's revolvers, and Cyrus McCormick's reaper impressed all viewers. Not only were the products up to and beyond European standards, but they were produced differently. The use of special-purpose machine tools impressed European manufacturers. The next year a delegation of British manufacturers and engineers undertook what would soon become a common pilgrimage to the United States to seek an understanding of the new American System of Manufacturing. Even though partially rooted in government armories, these new methods of manufacturing had already trickled into the civilian sector.

How and why did the mass production of military equipment transfer into the commercial economy? Why did this system develop in America? First, many of the machines and production methods originating in the armaments were almost immediately useful in manufacturing complex products in the civilian economy. These included reapers, sewing machines, and typewriters—and, later, bicycles and automobiles. As early as 1834, the Ames Manufacturing Company successfully produced machine tools by drawing upon the nearby Springfield Armory for models and personnel.

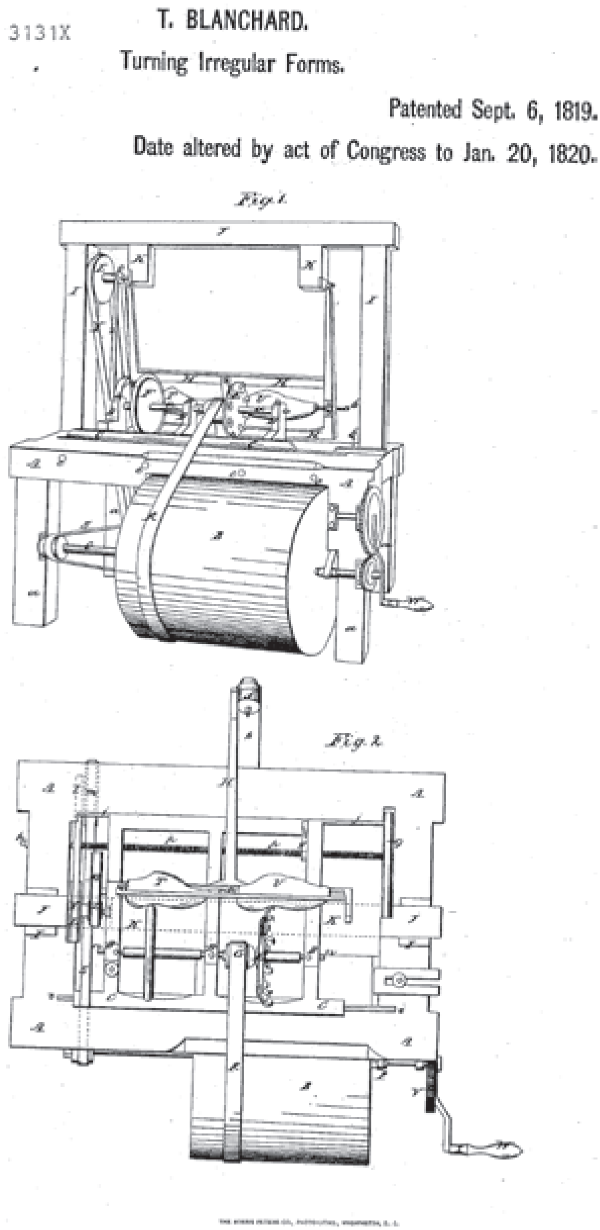

Figure 6.2 Patent drawings of Thomas Blanchard's 'pattern lathe' that copied irregularly shaped wood objects from 1819. This machines was widely used to manufacture gun stocks, saving much time over hand-made stocks with chisels.

Credit: *Courtesy of the United States Patent and Trademark Office.*

Colt, Remington, and Sharps did the same things to become successful private arms producers. And Remington, a maker of rifles during the Civil War, partially converted its machine tools to the manufacture of typewriters two years after the peace. Government, in effect, had done the research and development for the private sector.

What induced businessmen outside of the military sector to expend resources on machinery and quality controls that were not always obviously cost effective? The shortage (and thus high wages) of skilled American labor obliged employers to purchase expensive new machinery to offset labor costs. More importantly, perhaps, American craftsmen were mobile, with little long-term interest in any particular job. These crafts workers often pursued high wages wherever they could get them so that they could save enough money to buy land or set up their own business. All this made these artisans not only costly but unreliable to manufacturers. This provided an incentive to substitute new machinery for craft workers. At the same time, these skilled American workers seldom stood in the way of innovation. Unlike their more stable and tradition-bound counterparts in England, American workers had little objection to labor-saving technology because they had less attachment to a particular setting of work or way of work; and sometimes new machinery led to increased earnings (Figure 6.3).

Gradually, the problem of scarce, expensive, and unreliable skilled labor declined, but this did not remove the incentive to replace craftspeople with less skilled operators of specialized machines. If before 1850 the wages of the average American worker were a third or even 50 percent higher than those earned in England, this difference decreased gradually with waves of immigrants from Ireland, Germany, and England. The increased supply of unskilled immigrant workers from immigration provided an incentive from a different direction: Employers could pair cheap and docile immigrant labor with new machinery to replace high-priced skilled workers.

Still, the American incentive to substitute capital (new machinery) for scarce skilled labor was probably less important in explaining the adoption of the American System by private industry than *consumer market* factors: Early American consumers accepted practical, if homogeneous, durable goods. This American taste for pragmatism and dislike for ostentation can be exaggerated, however; just look at examples of late-nineteenth-century iron stoves or sewing machines for their ornate casings and cover designs. American manufacturers of many goods—especially makers of furniture, jewelry, and garments—continuously adapted to changing fashion to produce an enormous variety of consumer goods. Yet, as compared to the English, Americans were more tolerant of the merely utilitarian: An example is the common American table knife, with a handle and blade forged in one piece. This consumer attitude allowed manufacturers to dispense with the variety and changes of model that often frustrated a manufacturer's use of single-purpose machinery. Standardized machine-made goods did not necessarily mean a sacrifice of quality: Handmade shoes in Britain were ill-fitting and sometimes failed to distinguish between right and left feet. By the 1880s, American machine-made shoes were often superior.

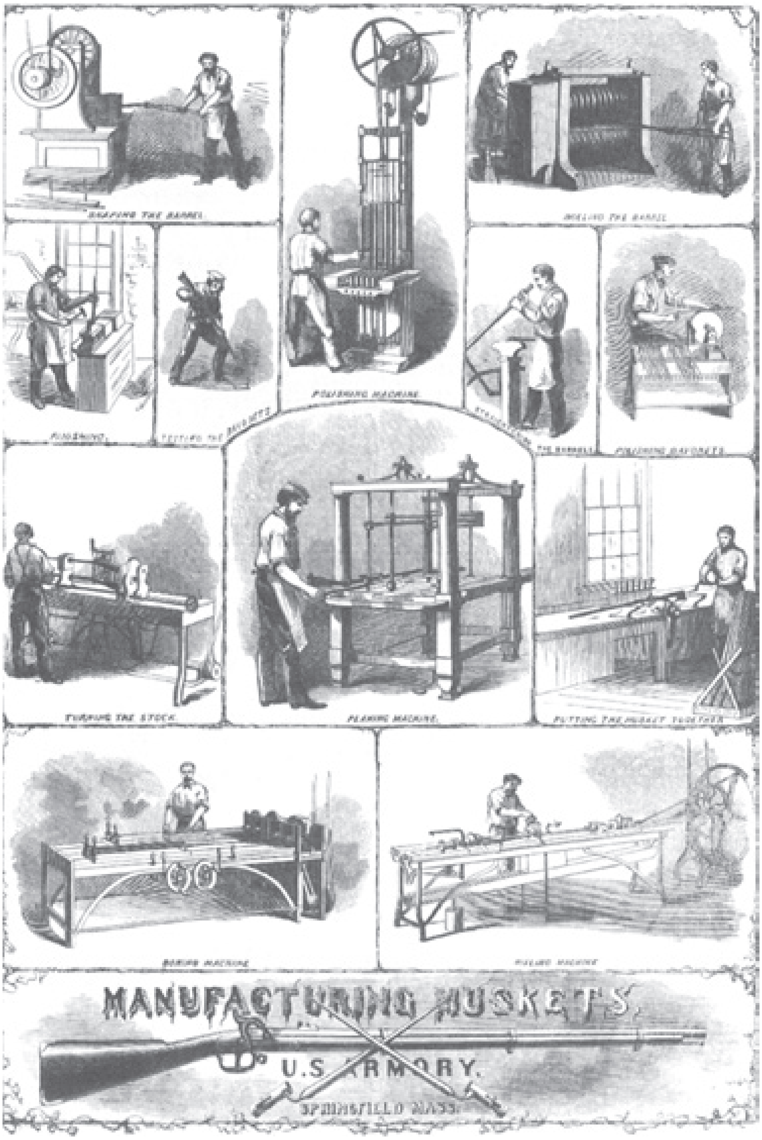

Figure 6.3 Machines used in the manufacturing guns at the Springfield Armory in 1861.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Another related example of this pragmatism was in the American innovation of 'balloon frame' housing that appeared in the 1830s. Americans constructed houses from manufactured two-by-four-inch studs, nailed every sixteen inches along two parallel boards to form a wall frame that could be erected to create simple boxes that, when roofed, became homes. This new method replaced the costly post-and-beam construction (see Chapter 2). As a result, more Americans could afford to be homeowners and to build larger houses. This construction, of course, facilitated the mass manufacture of studs, prefabricated window frames, and doors. Many could, and some still do, build their own houses, even if they were sometimes 'bald white cubes,' as one mid-nineteenth-century English observer mockingly called balloon frame houses.

The distinctive character of American consumer markets was rooted in the social dynamics of the United States. For example, rapid population growth stimulated demand for new goods, and the entrepreneur's faith that future markets would warrant expensive innovation. High birth rates did not lead to decreases in living standards, as they did in Ireland during the potato famine of the 1840s. Instead, a population boom in nineteenth-century America was not a problem because the country was expanding westward where land was relatively fertile (contrast to the interior of another continental settler society, Australia). American farming settlers (especially in the North) provided mass markets for utilitarian goods—axes, guns, plows, iron stoves, and eventually reapers and other goods requiring mass assembly. Even more important was the relative uniformity of demand, which made possible standardized plows, forks, and even toys. This homogeneity was based on the predominance of a rural middle class nearly unique to the United States: Eighty percent of Americans in 1810 were farmers and relatively few were impoverished; over sixty percent remained in this category in 1840. These farmers shared common practical needs for transportation and agricultural implements. Their relative isolation meant a demand for reliability and simplicity of repair. This market closely fit a technology that could mass produce simple low-priced goods with special purpose machinery.

Supply factors also played a role in producing the American System. A high land-to-labor ratio surely encouraged farmers to purchase relatively expensive farm implements like the reaper (see Chapter 7). And America's rich endowment of resources (such as wood) did not deter the introduction of new machinery like the pattern lathe, which was not only labor-saving but wasteful in the use of wood. As mentioned earlier, American circular saws used very wide blades that made much more sawdust than European counterparts. But they were far faster and required less maintenance and given the quantity of wood available in the United States (but not England), the waste was affordable.

Despite these advantages, Europeans often found American methods to be inferior. American machines may have been faster and more capable of detailed work but compared to the English they were often more susceptible to breakdown and wore out more quickly. This did not bother American industrialists because they expected that new machines would soon replace the old anyway. An American explained that poor construction of early steamboats was justified because faster steam engines would soon take their place. Within a decade of opening in 1817, a Rhode Island textile mill had replaced every one of its original machines. Europeans saw this commitment to constant change as shoddiness. Perhaps for this reason, they were slow in adopting American methods and machines.

We must stress that new machine tools were also slow to be introduced in many American industries. The American System was not necessarily cheaper, especially in industries where seasonal, short production runs were common. Hand labor required little investment or costly stockpiling of raw materials and finished inventory; in the large labor pools of cities, manual workers could often be hired and fired at will as the market demanded. This was particularly true in the fashion industries (especially apparel) that dominated in New York and Philadelphia even after 1900.

Complex and costly machine tools were often simply not necessary. For example, in the furniture industry around 1880, simple tools like a foot pedal-driven chisel for mortising were sufficient to increase productivity twenty-fold. Specialized pieces, continuous style changes, and perceived customer expectation of skilled artisanship kept the furniture industry in the semi-artisanal mode into the twentieth century. Marketing, more than manufacturing, determined the success of a furniture company.

Even industries that would seem ideal candidates for the new methods were laggard in adopting them. While some sewing machine companies (e.g., Wilcox and Gibbs) were early proponents of the American System, the Singer Sewing Machine company continued to use traditional methods for a generation after its founding in 1851. During those years of growth, Singer factories used few special-purpose machines, relying on hand filing for final assembly. The so-called European method of employing cheap labor organized into extremely specialized tasks prevailed until the end of the 1860s. Advertising, product innovation, and high retail prices (often eased by buying on credit) sustained many successful manufacturers of consumer goods, including Singer. By the early twentieth century, however, the American System prevailed in many industries.

Machinery and the Pride of Craftsmen

New methods of production brought new mechanical goods within the budget of many. These methods, however, also had a profound impact on the work experience, especially of skilled artisans. Special purpose machinery often replaced proud craftspeople with cheaper, less skilled operatives. Whereas the mechanization of textiles primarily affected women and children, the machine tool and mass assembly mostly changed the work of men.

The new machinery led to a decline in skill levels in trades like gunsmithing. Specialization of tasks made it possible to hire less-trained workers to bore or grind barrels. Machines like Blanchard's pattern lathe required only an attendant to install and watch the block of wood turned automatically into a gunstock. Wage work increasingly predominated in the armories.

At the same time, other occupations experienced little mechanization in the nineteenth century. Examples include the trades of butcher, shipbuilder, most construction specialties, and miners. It was only in the 1870s that artisan carpet weavers were replaced by machinery in Philadelphia. As late as 1907, a new product, the light bulb, was still manufactured largely by hand, with workers paid by the piece and aided by only simple machines. One large factory in 1901 used 21,000 different piece rates for its 27,000 employees!

The persistence of piece rates and simple machines in some industries did not mean that their conditions of work remained unchanged. In industries across the spectrum, managers increasingly attempted to raise output by imposing new rules on laborers. In 1818, Roswell Lee, manager of the armory at Springfield, tried to drive out the sociability of the workshop by abolishing fighting, gambling, and drinking 'ardent spirits.' As with the early textile towns, the management of armories encouraged church attendance and, with it, a commitment to steady work and devotion to family betterment.

This was not always an easy task, even where new machinery and rules were introduced; especially in rural frontier works like the Harpers Ferry Armory, religion and its habits of self-control were slow to gain a foothold. It was only 29 years after the armory was founded that the first church appeared in the area. In its 66 year history, these armory workers resisted change, associating disciplined work with slavery. In the 1820s, they continued to come and go as they pleased and took off from work during the hunting and fishing seasons. Rather than maximize income, armory workers who worked on a piece rate used the new machinery to work only as long as necessary to earn an acceptable income, reducing their workdays for more leisure and private farming.

Factory innovators in the more urban North also had difficulties in adapting workers to mechanization. Efforts to do so led to veritable cultural wars: On the one side stood managers who upheld the values of productivity and condemned what they considered the workers' 'vice' and 'lethargy'; on the other side were workers who valued personal liberty and mutual aid.

Only gradually did artisans begin to realize that machine tending was to be life's lot for most of their class, and that the traditional hope of becoming a 'master' of a trade had largely vanished. In this process, new attitudes emerged toward labor, wages, and time. Hours of work increasingly became periods of the day from which managers had purged traditional pleasures and the pride of skill. More and more, laborers understood that they were selling their time during the day's work rather than participating in a 'way of life.' Mechanization gave employers a method of regulating the pace of work. The machine obliged the worker to submit to the hours and intensity of labor, which were dictated by the employer. Managers placed a monetary value on the working hour and sought to increase how much a worker produced in that hour. Managers encouraged punctuality and sought to reduce absenteeism with threats of fines and firing. Many employers replaced day wages with pay by the hour, thus lowering wage costs when slack demand meant less than a 'full' day of work. As we have seen, other employers adopted pay set by the number of pieces produced in order to encourage workers to increase their daily output.

Laborers responded in kind to these efforts to intensify the workday. They attempted to enforce limits on output, ostracizing workmates who produced more than what the group insisted was an appropriate 'stint.' To work more only meant exhausted, divided, and jobless laborers, they claimed. Workers also demanded overtime pay and a cap on the length of the 'normal' workday. We see evidence of this change when skilled urban workers demanded a ten-hour day in the mid-1830s, reducing the workday by one or more hours. The depression of 1837 frustrated this broad-based movement, but it was revived repeatedly in the nineteenth century. These wage earners were hoping to extract from employers a larger share of the economic gains of increased productivity. By reducing the workday, wage earners hoped to give more workers jobs and to make seasonal employment last longer.

Sometimes laborers demanded shorter workdays because they believed that it was their right to a life beyond work and the market. A group of workers from Boston claimed in 1835 that their duties as 'American Citizens' prevented them from working more than ten hours per day. In effect, they argued that machinery made it possible for workers to participate in American cultural, political, and religious life—if working hours were reduced. The gradual purging of leisure from work also obliged workers to reclaim leisure after working hours. Finally, the separation of work and domestic life resulting from the removal of materials and machines from the cottage led workers to embrace a clear separation of work and 'life' as the only practical defense of family time. The common option of withdrawing the mother from wage work was only a partial solution. Not only did workers attempt to make labor time into more money, they also sought a life free from the machine.

Nevertheless, despite protest, American wage earners were hardly revolutionary. With mechanization and intense work came higher wages that softened labor discontent. On average, real wages rose 50 percent between 1860 and 1890 (a good deal of this coming from lower consumer goods prices). However, historians have also noted how the increasing division between high- and low-paid workers explains the failure of a mass socialist movement in the United States. The gap between the best- and worst-paid industrial workers in the North increased 250 percent between the 1850s and 1880s. Skilled and semi-managerial workers (especially in metals, construction, and printing) gained far more from the improved productivity than did machine tenders in textile and other trades. Immigrants constituted over half of the industrial workforce, and their numbers were heavily concentrated in the low-wage sectors.

These divisions by income and ethnicity prevented unity among workers, and this helps explain why the assault of mechanization on skill and security did not produce even greater protest in the nineteenth century.

The mechanization process that began with the spinning mill culminated in the mass production of machines. Americans played an important, but by no means exclusive, role in this transformation. The result was a democratization of goods, but also work that frustrated many and from which some sought escape.

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7 Machines on the Farm and in the Forest, 1800–1950

The steam engine and machine tools that revolutionized transportation and industry also transformed life on the land, and changed how Americans were fed and supplied with natural materials. New tools and processes eased the farm family's work and made American agriculture a wonder of productivity around the world, but technology also forced that same family to accept often unexpected or unwelcome changes. Many willingly (but others less obligingly) left the farm, gradually ending America's self-image as a nation of family farmers. Food that had been home- or locally grown became mass processed and packaged. But soil that seemed to supply endless fertility suffered erosion, and forests were stripped of trees. Mechanization solved, but also created problems. In this chapter, we will paint in broad strokes a picture of how mechanization transformed the farm and forest from 1800 to about 1940 (with discussion of the later period following in a later chapter).

Innovations in Cultivating and Harvesting

Many people assume that farmers are slow to take risks and to introduce new methods or tools. Although in 1800 American settlers were free from the constraints of peasant servility and village tradition known in Europe, New World farmers were still burdened by their economic and cultural isolation and the sheer demands of clearing land. There was little time or ability to experiment. For many farmers, the routine of growing crops and tending livestock had hardly changed from the earliest colonial days until well after 1800.

This was not because farmers were disinterested in improvements. But agriculture was subject to unyielding demands of the weather and the soil. Not much could be done to speed up the growing season. And, an innovation that made one part of the cycle more efficient might not be advantageous until it was accompanied by other related innovations. For example, in 1731 the Englishman Jethro Tull had developed an effective 'seed drill.' This device mechanically planted wheat in rows through tubes that dug holes in the soil. American farmers, however, found that the rocky and stumpy fields of colonial America made this machine nearly unworkable. Thus, many farmers continued to drill seed by hand, using a pointed stick until they settled on fields better suited to the seeding machine.

Even so, Americans had strong incentives to find labor-saving machinery. This was a special problem in the early United States, where labor was in short supply but arable land was plentiful. Seemingly limitless fertile soil made farmers dream of new tools to maximize their harvests and to avoid loss—due to a shortage of workers and thus an inability to get the grain into the barn before it spoiled or fell to the ground.

Let us quickly survey some major agricultural innovations, improvements on the traditional farm implements and methods discussed in Chapter 1. American farmers had good reason to reduce the drudgery of the plow. Thomas Jefferson, like other enlightened gentlemen farmers of his generation, experimented with a standardized and efficient plow design that would continuously lift and turn over the soil. In 1797, Charles Newbold of Burlington, New Jersey, patented a cast iron plow to replace the heavy ironclad wooden plow. The iron plow increased the efficiency by up to one-half over wooden plows. Still, the heavy sod of the Midwestern prairie stuck to the iron moldboard, forcing the farmer to scrape it off with a wooden paddle every few feet. Because this soil was so rich (extending down four feet and more), farmers from the rocky hills of Vermont and New York were naturally attracted to the Midwest. But the Midwestern prairie became practical to farm only after this problem was solved.

John Lane, a blacksmith from Illinois, offered an answer with his polished steel moldboard that overcame the problem of sticky soil. Failing to patent his invention, he left it to John Deere in 1837 to market a wrought iron plow with a steel-covered parts. When Deere moved production to Moline, Illinois, in 1846, his plow was purchased by thousands of new settlers on the prairie. The plowing requirements of the new giant farms of the Midwest and West stimulated the development of multiple 'gang' plows attached to a team of horses that could turn up to seven acres per day.

The next traditional task of cultivation—harrowing—was also improved in the 1840s. The new harrow, with iron frame and spikes, replaced the traditional wooden harrow. In 1854, another American patented the double-rowed disc harrow that worked more smoothly than the traditional spike harrow. By 1869, the adjustable spring-tooth harrow had overcome the old problem of the spikes or disc being caught on rocks and sod, adapting the tool to uneven ground. In 1840, Pennsylvania inventors Moses and Samuel Pennock produced an adjustable seed drill that could accommodate a rough field surface. In 1853, George Brown of Balesburg, Illinois, patented a corn planter pulled by a horse. A lever opened hollow stems that delivered corn seed and rollers pressed the seed into the soil.

These innovations were important, but the key problem of harvesting remained. Here the gap between the American agricultural potential and its limited labor supply was widest. Within about ten days after ripening, wheat had to be cut or reaped. After that time, the grain began to fall on the ground and was largely lost. American farmers lacked Europe's large and growing supply of rural laborers. This was especially true of farmers in the vast and fertile, but underpopulated, regions of the Midwest. They were eager to find a substitute for the traditional sickle or scythe to cut mature stalks of grain. The introduction of the cradle in the 1780s from Europe improved matters a little. This long blade with its attached five long wooden fingers, designed to catch reaped grain, was a labor saver—doubling or tripling the output of the sickle. But it was hard to use in the heavy stands of grain that were typical in the United States, and it did not reduce the backbreaking job of gathering and binding cut stalks into 'shocks' for threshing. Farmers longed for an even faster way of doing this labor-intensive and time-sensitive job of harvesting.

Farmers needed the reaper to solve the harvesting problem. Cyrus McCormick (1809–1882), the American who most people identify with the reaper, was hardly the first to invent this harvesting machine. An early patent, taken by the Englishman Joseph Boyle in 1800, consisted of a rotating circular plate, to which were attached a series of scythes. Without a way to hold the stalks of wheat upright before cutting or to collect the harvested stalks, however, Boyle's machine was useless. This was an attempt to duplicate with a machine the hand method of harvesting. In 1826, another Briton, a clergyman named Patrick Bell, offered a radically new design: The cutting mechanism consisted of a row of thirteen triangular blades placed in a horizontal bar located a few inches above the ground; these blades worked like shears to clip wheat stalks. A large wooden reel pushed the grain into the cutting bar and thereafter onto a moving canvas that regularly deposited the grain on the ground. A team of horses pushed the machine (so that the animals would not trample the plants), turning a ground or bull wheel that provided the power for the moving parts. Five years later Cyrus McCormick offered a slight variation: The horses pulled his reaper from the side (more efficient than pushing, but also avoiding trampling), and the cutting bar consisted of a series of stationary metal fingers that held the stalks while they were sawed off by a reciprocating horizontal blade (Figure 7.1).

Cyrus McCormick was less original than is often assumed. In fact, from his rural roots in western Virginia, he simply followed his father's twenty-year quest to make a practical reaper. Even then, long after this farmer/blacksmith built his first successful machine in 1831, McCormick failed to capitalize on it—despite the reaper's obvious importance to American agricultural development. His early models were troubled by breakage, especially on the hilly and rocky fields of western Virginia. McCormick also lacked the capital and mechanical expertise to manufacture his reaper. He did not sell his first machine until 1840. McCormick was obliged to travel widely, running his reaper in contests against cradles and against the machine of a competitor, Obed Hussey (whose design was similar to that of Bell). McCormick appeared personally at

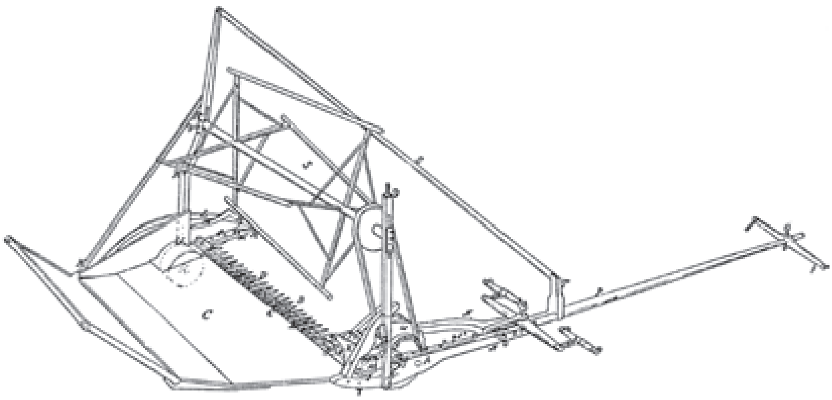

Figure 7.1 A 1845 sketch of a McCormick's reaper. The horse would be attached on long pole on the right. Note the 'bull wheel' on the ground that powered the turning of the reel and the motion of the horizontal cutting blade (to the left).

Credit: *George Iles,* Leading American Inventors, 1912*, 300.*

the London Exhibition in 1851 to advertise his device. Only in the early 1850s, when he copied the cutting bar used by Hussey and Bell, did McCormick's reaper become the all-purpose machine that would sweep the Midwest.

Commercial success required more than just a well-known and satisfactory machine; a large potential market among farmers was also necessary. In 1847, McCormick found that market when he moved his manufacturing to Chicago, Illinois. There, near the vast expanses of the Midwestern prairie, he found wheat growers on extraordinarily rich land but without workers to harvest the grain. The reaper was a dream come true for these farmers. McCormick's decision roughly coincided with the first railroads that reached Chicago. Within the decade after 1856, the railroad linked the prairie grain grower to the expanding Eastern (and, via the steamer, international) markets. The reaper was the key to the exploitation by Midwestern grain growers of this new global demand for cheap wheat (in the process, displacing Italian farmers, some of whom emigrated to the United States). From Chicago, McCormick developed a network of small-town sales agents who cultivated personal contacts with skeptical farmers and offered purchase by installment. Thus, he was able to dominate the reaper business. He also continuously improved his machine, adding attachments to assure his leadership in the farm implement industry. McCormick's reaper was not cheap (retailing at $130 in 1860 when skilled workers earned about $1.60 per day), but it operated well on the rich flat lands of the Midwestern prairie. Farmers, assured of bountiful harvests and burgeoning world markets, and facing shortages of seasonal harvest labor, were more than willing to make the investment. Some 3,500 reapers replaced 17,500 harvest hands in 1852 alone in the Great Lakes states.

When the Civil War drained the countryside of young men (and raised grain prices), farmers responded by purchasing in 1864 alone as many reapers as they had in the previous 28 years.

The reaper on flat land could harvest twelve acres per day (the equivalent of five cradles). It still required a worker to drive the horses, another man to rake the grain or fodder off the platform onto the ground, and up to eight others to bind and shock the wheat stalks for threshing. In 1854, the invention of a mechanical rake eliminated one man. The twine binder invented by the American John Appleby in 1878 saved additional labor: A curved needle wrapped and knotted twine around a sheaf of freshly cut wheat stalk, which was automatically raised by a conveyor and dropped for later pickup.

There remained the problem of separating the grain from the stalk in threshing, the traditional job of the flail. By the 1820s, a cylindrical thresher studded with spikes greatly eased this task. Animal treadmills soon powered these machines. They could process one- to five-hundred bushels of wheat per day (as compared to eight by the traditional method). By the mid-1830s, there were seven hundred different types of threshers sold in the United States. In 1837, a mechanical winnowing sieve was marketed that shook the grain and allowed the straw to separate. J.I. Case became a major producer of these threshing-winnowing machines. In the 1850s, threshers were beginning to be powered by steam engines, which were often hauled by a team of horses into the field (Figure 7.2).

Figure 7.2 A 1903 combine (harvester and thresher). Note the number of horses, and the flat terrain, required for this 'monster' machine.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

A working 'combine' that both reaped and threshed appeared in Kalamazoo, Michigan, as early as 1836. Its inventors, Hiram Moore and John Hascall, combined the reaper's reel, reciprocating cutting bar, and conveyor with a cylinder threshing device. The entire mechanism was powered by two 'bull wheels' that turned on the ground when pulled by a steam tractor or team of horses. This combine was used fairly widely on the huge wheat farms of California from the 1880s. The Moore/Hascall combine required a very large team of horses, which made it impractical for the average family farmer. It was only with the development of the gasoline tractor, and other improvements in threshing machinery, that the combine would replace the self-binding reaper. And this was only beginning in the 1930s.

A power source that seemed to promise much but was slow to deliver was the steam engine. As early as 1830, David Ramsey filed an English patent for cultivation by steam tractor. The weight and cost of early steam engines, however, made steam traction a poor substitute for the animal's pulling power. Self-propelled steam-powered combines appeared in 1886. However, they had many disadvantages, requiring a crew of seven men, including a fireman, water hauler, and driver. They were often fire hazards. Although some steam combines could cut a hundred acres a day, they weighed fifteen tons or more and were hard to handle. Most important, they were less efficient than horse-drawn models that needed only three men.

Steam tractors were marketed in the United States only in 1873. By the 1890s, monster steam tractors, weighing as much as twenty-five tons, hauled up to thirty plows over 75 acres per day. Only the huge farms of the Dakotas could profitably use these giants. And even these mammoth farms often failed in the 1890s. Given the poor shape of country roads, steam tractors frequently were mired in the mud, and wooden bridges collapsed under their weight. Steam tractors were used mostly for threshing grain rather than plowing or harvesting. In its heyday, about 1910, only 5 percent of grain farmers owned a steam tractor.

Perhaps the most important improvement came in 1892 when John Froelich built the first internal combustion/gasoline tractor in Waterloo, Iowa. Many others soon followed. Unfortunately, like their steam competitors, early models were too large, expensive, and unreliable to convince many farmers to give up their horses and mules. In 1913, the Bull Tractor Company in Minneapolis offered a relatively light tractor (4,650 pounds) at a mere $650. This 'Bull with a Pull' soon inspired established implement manufacturers like John Deere and International Harvester (descendant of the McCormick reaper) to manufacture cheap but durable gasoline tractors. Car maker Henry Ford, always a farm boy at heart, joined the fray with his Fordson tractor, an adaptation of his even more famous Model-T automobile (Figure 7.3).

Slowly, innovations in planting and harvesting transformed the farm. No matter when the initial invention appeared, farmers embraced a cluster of new machines at about the same time, especially in the 1840s and 1850s. These innovations appeared when and largely where they did because of the

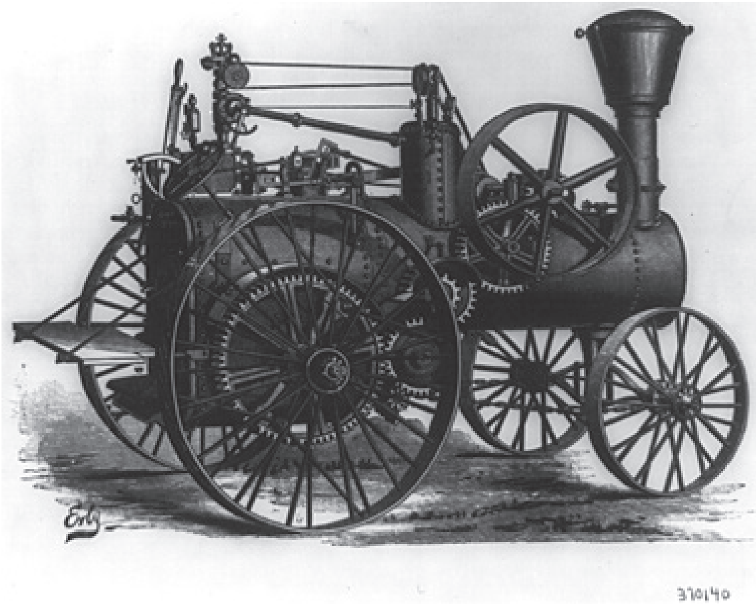

Figure 7.3 An 1885 steam tractor that would have been used to pull a plow or other farm implement. Note its size and how difficult it would have been to use especially on a small farm.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

opening up of the Midwestern breadbasket. Mechanization did not necessarily increase output per acre. Rather, it allowed individual farmers, especially in the Midwest, to raise their productivity by expanding acreage.

But the advantages of technology were very unevenly distributed. While disc gang plows, seeders, reapers, and threshers increased the productivity of the wheat farmer by 18 fold between 1830 and 1896, technology had practically no impact on the tobacco farmer and little on the cotton farmer in the South. The character of tobacco and cotton cultivation and the South's legacy of slavery help to explain this fact. Tobacco farming remained labor intensive. Farmers placed tobacco seedlings into carefully cultivated mounds for drainage and aeration. Continuous manual attention was required to thin and weed tobacco fields. From midsummer, farmers had to selectively harvest tobacco leaves because they matured at different rates. Mechanization of cotton harvesting also proved difficult and would have occurred slowly in any case. After the abolition of slavery in 1865, a system of sharecropping (where African-American farmers with little capital rented white-owned land paid with a portion of the harvest), perpetuating technological backwardness (as well as black poverty) until mechanization came in the 1940s.

Perishables and Packing Houses

Early American farmers were constrained by the limits of their machines' abilities to adapt to the problems of growing food on irregular fields and other restraints of nature. But producers and consumers of food were also confronted by the difficulty of storing and preserving foodstuffs. While grain and flour (along with a few hardy vegetables like beans) could be kept until the next harvest, most food rotted naturally shortly after harvesting, making the seasonality of most crops a big problem for both farmers seeking markets and consumers desiring year-round access to favorite foods. In 1800, few urban dwellers even had root cellars, much less iceboxes, in which to store vegetables or fruits. Farmers could count on only a few weeks to sell berries, tomatoes, and many other fresh non-cereal crops. Old techniques like drying, pickling, and smoking meats were essential ways of extending the edibility of meat after butchering. Converting milk into butter and cheese was a similar solution to the problem of preservation. Farmers fermented their annual surpluses of highly-perishable fruits like berries and even apples, wine, and hard cider (or added sugar to make jams). The surplus of grain found its way into jugs as whiskey and beer.

But these solutions were hardly sufficient, especially for an expanding agricultural sector in nineteenth century America, often distant from population centers on the east coast. Faster transport and refrigeration helped alleviate the problem of perishable foodstuffs. By the 1850s, orchards and vineyards in California and Florida were already supplying Northeasterners with fruit by rail. With the appearance of the refrigerated railroad car after the Civil War, this commerce increased dramatically.

Complementing the benefits of speedier delivery of foodstuffs to market were the efforts of farmers to extend the growing and harvesting periods of popular food crops. For example, by the end of the nineteenth century, farmers and seed companies had developed new varieties of tomatoes that matured earlier than the late summer (as was common with this crop), thus extending the time when fresh tomatoes would be found on the market (and increasing farmers' income), eventually leading to access year-round. Also important was the development of techniques to grow vegetables in hot houses in the winter, again overcoming the age-old problem of the short growing season, especially in the North.

Speed in delivery of food and extending the availability of fresh vegetables and fruits only solved part of the problem. Another issue was home storage. Only in the 1820s did an improved ice house allow ice to be stored throughout the year in warehouses, cut by farmers from lakes in winter and distributed to consumers in the warm months to keep milk, meat, and other perishables cool and safe. Artificial ice was produced commercially from the 1870s, supplying the home icebox that, until the 1940s, was filled weekly by icemen in horse-driven wagons. As we shall see in Chapter 12, commercial canning, packaging, and freezing (along with domestic refrigeration) further widened the mass market for perishable foodstuffs.

Milk and cheese production also underwent a slow but profound transformation. After about 1830, this traditional job of farm women was gradually taken over by commercial cheese factories—but without major technological change. Rapid shipment of dairy products by rail and improved domestic refrigeration naturally stimulated demand for cheese and milk. Meanwhile, market production of milk products encouraged animal breeding, improved barn shelters, and mechanized feeding. Pasteurization (heating raw milk to remove disease-causing bacteria, a problem in milk that traveled some distance) was introduced in the late 1880s. More crowded dairy barns stimulated the study of animal medicine and disease control. Increased dairying also encouraged the development of silage—the feed grass, grains, and legumes cured in silos. Only after curing in storage could sorghum be used as feed, and silage helped cows produce more milk than did hay. The shift to dairying in the Northeast and Midwest (along with truck farming) may have saved these regions from the ravages of soil erosion experienced in the Midwestern plains and South.

New machinery also played a role in the new dairy farm. The centrifugal cream separator of 1879 greatly sped up the traditional gravitation method of skimming cream from raw milk. By 1914, after many experiments, the first practical milking machine appeared on the market. With the incubator of 1885 and feed carrier of 1897, poultry farming developed into a specialty. A key innovation was the use of electric lighting to trick hens into laying eggs in the darker winter months when they naturally stopped or slowed down producing eggs. Both dairy and poultry production traditionally had been the work of farm women. In the nineteenth century, with new technology, these industries gradually became the preserve of male farmers and industrial corporations.

The opening of the Midwest was closely linked to the reaper. But the economic success of westward expansion also depended upon mechanized meatpacking. Grain growing and livestock raising were naturally related. Farmers in the Ohio River Valley fattened thousands of pigs and cattle with their corn and grain. The problem remained of how to get this meat to market. Pigs and cattle had to be driven to Eastern towns on the hoof. Inevitably, meatpacking centers emerged to save farmers this effort. The first center, appropriately enough, was Cincinnati, strategically located on the Ohio River. From the 1830s, as cool weather set in, farmers drove long lines of pigs to Cincinnati's riverfront slaughter houses. Poor refrigeration and high volume encouraged meat packers to make the process as rapid as possible. By about 1850, meat cutters worked along veritable 'disassembly' lines: Animals were driven up an incline to the top of a four-story building. Then they were led singly down a chute to be struck with a mallet, bled, and systematically cut up.

With the opening of the Great Plains came the spread of cattle herding, replacing the buffalo, which had been nearly exterminated by 1880. After 1845, longhorn cattle from Mexico were introduced to the Southwest, making the United States a global center of beef production, enticing investors from as far away as Britain. Soon thereafter the open range was replaced by two simple, but vital, inventions. First, the silo appeared in Illinois in 1875 for storing feed. This allowed cattle owners to abandon the practice of grazing animals on the open range. Second, the barbed wire fence, introduced in 1874 by Joseph Glidden, gradually broke up the range and enclosed the herds on private ranches.

All this beef on the hoof raised the problem of delivering fresh meat to Americans, most of whom lived in the East. As earlier, these cattle had to be driven to distant markets and costs were prohibitive. In 1867, Chicago livestock dealer J. G. McCoy provided a solution when he connected the cattle trail with a rail line at Abilene, Kansas. The train took cattle to Kansas City, Milwaukee, and especially Chicago for butchering. In 1865, work began on the Chicago Union Stock Yards. This 120–acre complex was criss-crossed with alleys that delivered thousands of pigs, cattle, and sheep to open pens for distribution to butchering centers. Within twenty years, the Union Stock Yards was surrounded by a hundred-mile maze of railroads that sent meat to every corner of the nation. This, however, required preservation. Between 1868 and 1878, Chicago-based meatpackers gradually developed efficient refrigerated railroad cars to ship fresh meat back East. Gustavus Swift cooled meat suspended on hooks with ice stored in the ceilings of his cars. This simple method of transport helped him to conquer the New York meat market. Others, like J. A. Wilson, took another path to exploit this huge vortex of animal flesh: In 1875, he patented a process for canning corned beef.

Chicago became a center for innovative meatpacking. By 1882, Chicago meatpackers used a decoy pig lured with food to lead a line of pigs down a narrow track; the pigs' legs were tied by chains to an overhead rail; then the floor of the channel was dropped slowly, suspending the pigs and leading them to slaughter and dismemberment. Mechanization was not always easy, however. Despite many efforts to mechanically skin and cleave the hog, the irregularity of the animal continued to require handwork. Nevertheless, the organization of the process, with the most minute division of labor, made quick work of turning a pig into pork (Figure 7.4).

The old farm chore of slaughtering a pig or cow in the autumn for family use had become a centralized, mechanized business. The consumer was spared the bloody task of killing what they ate. And fresh meat could be found year round.

The Wonders of Biological Innovation

Machines alone did not transform agriculture in the nineteenth and early twentieth centuries. Mechanization often worked in tandem with plant or animal breeding; and biological innovation by itself accounts for much of the expansion of cultivation and herding. For example, the cotton gin fostered the planting of short-stable cotton in the interior rather than the long-fiber Sea Island cotton that could be grown only along the coast. The gin allowed a worker to

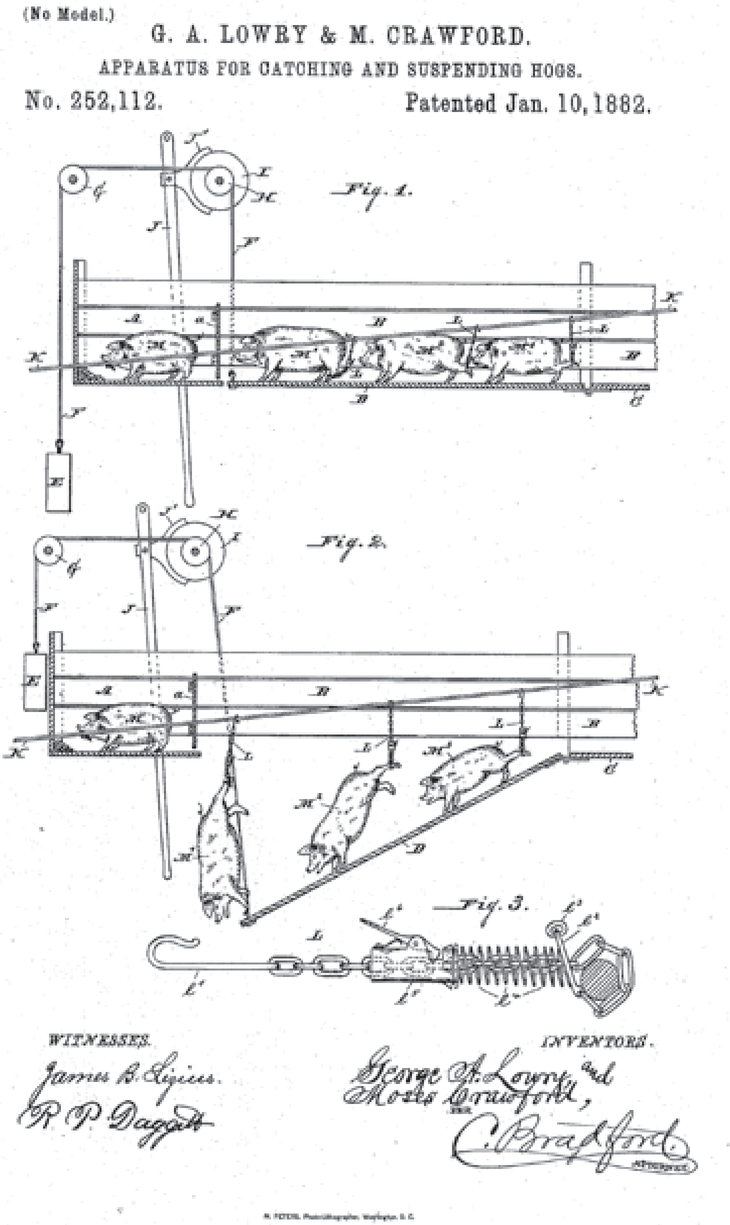

Figure 7.4 This 1882 patent for preparing a pig for slaughter indicates what measures mass-production butchering took to ease the disassembly process.

Credit: *Courtesy of the US Patent and Trademark Office.*

clean 50 pounds of cotton a day, and with steam, the gin became much more productive. The result was an increase the production of cotton bales per year from 3,000 in 1790 to 3.841 million in 1860, with cotton comprising 60 percent of the value of US exports. This led to the expansion also of slavery in a 'Black Belt' zone extending from central South Carolina to East Texas, where a majority of the population was slaves by the Civil War. Cotton output also increased due to the introduction of Mexican varieties of short-staple cotton, the bolls of which ripened more uniformly and packed more easily, tripling the productivity of slave labor. Similarly, the development of Bright Leaf tobacco, along with the introduction of flue curing, made possible a milder smoke. This led eventually to the widespread use of cigarettes (and with it the habit of inhaling the smoke, contributing mightily to the disaster of nicotine addiction and deadly disease).

Sometimes the major innovation was the importation of new plants and animals from abroad. Nineteenth-century American farmers introduced a wide variety of grains, beans, and grasses from Europe and elsewhere that fed their livestock. As importantly, drawing on late eighteenth century English innovations, Americans bred their cattle, horses, and pigs to enhance desired traits (for milking or meat, for example) or adaptability to the environment (like the Texas Longhorn). These profitable herds were often the product of the hiring out of prized bulls for breeding. Scientific discoveries concerning animal nutrition around 1900 led to healthier and more profitable livestock.

All this, along with innovations in shipping, led to regional specialization. For example, dairying had been a local, often haphazard, enterprise before the nineteenth century. Due to breeding, improved nutrition, and other innovations, however, output of milk per cow increased as much as 4.6 times from 1800 to 1940. These changes made possible milking year round inswtead of the four or so months of milk production per year before 1800. This transformed the dairy industry, centering it in areas like Wisconsin by the end of the nineteenth century.

Beginning in 1862, the US Department of Agriculture and the Morrill Act that funded land grant colleges (each with training in farming and engineering) fostered scientific approaches to agriculture, especially the spread of new more productive and disease-resistant crops and improved animal breeds. The Dakotas, Nebraska, and Kansas were still covered in grasslands feeding vast herds of Buffalo in 1870 and were largely passed over by pioneers moving west. Thereafter these plains states were transformed thanks in part to new well-adapted varieties of grain. By 1900, this region supported almost 400,000 farms, becoming America's Wheat Belt.

The Social Impact of Mechanized Farming

Technology transformed the labor of farmers, and the ways that all were fed. Mechanization raised productivity and reduced the demand for agricultural labor (see Figure 7.5). Output per farm worker increased threefold from

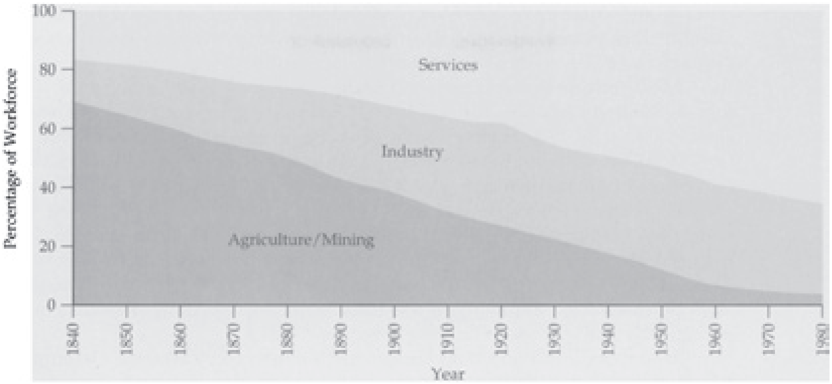

Figure 7.5 Notice the radical decline of the proportion of Americans employed in agriculture since 1840.

1841 to 1911. 60 percent of this increase in productivity is attributable to mechanization (again mostly by increasing the acreage cultivated per farmer). Agriculturalists, especially in the North and West, embraced machinery at least as hopefully as did manufacturers. From 1790 to 1899, some 12,519 United States patents had been issued for harvesters, 12,652 for plows, and even 1,038 for honeybee production.

Farm machinery and processes surely saved time and labor, but they also created dependency. Farmers who lacked skill or capital found that they could not keep up. They fell behind on payments for the new machines and other innovations, and many drifted into debt. Between 1880 and 1900, the proportion of Kansas farmers who were obliged to rent land grew from 1 percent to 35 percent. Increasingly, farmers had to specialize in order to purchase costly new equipment, livestock, and seed. When a farmer bought a Farmall tractor on credit, the bank demanded payment, whatever the outcome of the harvest or the price per bushel of wheat. Mechanization and biological innovation benefited the richer and larger-scale farmer over the more marginal cultivator and escalated the trend toward the consolidation of lands.

We should be careful not to romanticize the family farmer with his team of horses and his wooden plow. If machines led to millions leaving the farm, many of these people eagerly embraced the regular hours and less physically demanding work of office and factory. Moreover, the machine spared the remaining farmers much travail. By the 1940s, the gasoline tractor saved farmers 250 man-hours per year by eliminating the time lost in caring for draught animals. The number of horses on American farms peaked in 1920 at nearly 20 million. With the coming of the gasoline tractor this dropped to 13.4 million by 1930, and 5.4 million by 1950. Between 1918 and 1945, 45 million acres were released from growing animal feed and made available for other purposes. By the 1920s, the tractor had become a status symbol, a sign that a farmer was modern, equal to the city slicker.

Felling the Forest by Machine

In the view of early Americans, clearing the land of forests was an essential act of civilization. This was no simple task. A farmer in 1800 with nothing more than an axe and hoe took about ten years to clear and fence a hundred-acre farm. Few technologies became available to ease this work in the first half of the nineteenth century. Nevertheless, Americans cleared 113 million acres of forest before 1850. Farmers could spend a month per year on their woodlots of 10 or 20 acres, cutting timber for use in heating and cooking.

Trees were more than a nuisance to farmers needing cleared land. Wood long remained the primary heating and cooking fuel, even for urban Americans. Unlike the British, Americans were slow to adopt coal. Wood remained the mainstay in building construction throughout the century, and Americans only slowly abandoned charcoal in iron furnaces and wood fuel for steamboats and locomotives. American per-capita wood consumption was five times greater than that of England in 1860.

The insatiable demand for wood led to a rapid westward movement of the lumber industry. In 1839, two-thirds of American lumber came from the Northeastern states. By 1859, that percentage had been reduced by one-half, with the Great Lakes and Central states taking up the slack. Along with the westward movement of lumbermen came new technologies that quickened the pace of cutting: The circular saw appeared in 1814 in the United States, although it was widely used only from the 1840s, when replaceable teeth were invented. An alternative, the band saw, was equally slow to be adopted by American lumber mills. The first band saws of 1819 were widely adopted only when improvements in steel increased their durability in the 1870s. After 1850, planing machines that shaved smooth surfaces on lumber made possible the manufacture of flooring boards and boxes.

Even more important than lumber-milling machinery was the lowering of transportation costs: Up to two-thirds of the cost of clearing the forest was absorbed in shipping timber from forest to mill. This expense of getting lumber to market was one important rationale for clear-cutting an area. Trees were often felled in the autumn and early winter, mostly by lumberjacks with long-handled axes. The gasoline-powered chain saw appeared only in 1927, but its widespread use had to wait until after World War II. Then the logs were 'skidded' to a river's edge on sleds to wait for the Spring, when high water allowed the 'log drive' downstream. Logs had to be 'marked' in much the way that cattle were 'branded' to identify their owners. Log jams were common.

The movement of the lumber industry into the upper Midwest coincided with further mechanization. Between 1865 and 1875, improved band saws, combined with lumber-feeding and log-turning mechanisms, radically reduced the labor required for milling lumber. Steam power rapidly took over, creating the conditions for highly centralized and large-scale lumber mills. At the same time, railroad tracks deep into forests supplemented older ways of transporting logs to mills. The rate of forest exploitation increased dramatically in the Great Lakes states, rising from the four billion board feet cut in 1873 to an annual peak of almost nine billion by 1900.

This inevitably led to barren forest land. By 1920, the harvest of lumber was down to one billion board feet per year. A generation of clear-cutting had its price. The lumber town of Cheboygan, Michigan saw its industrial base drop from 96 mills in 1896 to eight in 1939. Probably 50 million acres from Michigan to Minnesota were cut bare by 1920. Unlike the selective clearing of Eastern forests, the Lakes states' forest land was far more thoroughly cut. In any case, the poor soil and climate made these lands of little agricultural value afterward, despite efforts to convert deforested land to farming.

A similar process occurred after 1880 in the forests of the American Southeast. Pine logs were fed into mill towns across the Deep South. This boom peaked about 1910, only to decline sharply in the 1930s. As in the North, timber men tried to sell cut-over land to would-be farmers, but again with mixed results. The Pacific Northwest was the last frontier of the lumber mania. The boom lasted roughly from 1900 to 1940, climaxing at 14.1 billion board feet in 1929. Frederick Weyerhaeuser, whose fortune was made in the Great Lakes forests, shifted his operation to Washington State in 1900. Rapacious lumbering reached its high point in the 1920s in the Northwest, as companies sought quick returns on their large investments in the mammoth and nearly inaccessible old forests.

Reversing the devastation of the nineteenth century took time. By the 1930s, use of caterpillar tractors lowered the loss of seedlings caused by log 'sledding,' and made more selective logging possible. The shift from rails to logging trucks came also in the 1930s, and actually reversed the trend toward business concentration in the lumber industry. Even more critical was a reduction in the demand for wood for fuel. If 85 percent of American energy came from wood in 1850, by 1910 only about 20 percent came from the forest, most of the slack taken up by coal.

Attitudes toward the forest slowly changed. As early as 1847, the Vermont naturalist George Marsh wrote that clear-cutting practices were eroding soil and undermining future growth. Others were interested less in sustainable agriculture and forestry for economic advantages than in retaining ancient forests and untouched wilderness for aesthetic reasons. Perhaps best known is John Muir, whose quasi-religious evocations of the beauty of California's Sierra Mountain forests did much to encourage the movement to establish National Parks in the 1870s and 1880s.

Congress created the Division of Forestry in 1879 and passed legislation in 1891 that provided for Forest Reserves safe from commercial exploitation. Still, it was only with the leadership of Gifford Pinchot between 1898 and 1910 that the federal government began to take an active role in encouraging forestry management to assure sustainable yields of timber. The Forest Service, created in 1905, had the authority to manage lumber harvests. In 1916, the National

Park Service was established to conserve scenic and wildlife areas from commercial exploitation. By this time, private timber companies were also ready to seek government aid to prevent fires, facilitate selective cutting, and adopt forest thinning practices to maximize tree growth. The ultimate solution was reforestation. In 1890, the botanist Charles Mohr advocated that forest land be replanted with a fast-growing pine. In 1941, the first tree farm was planted in Washington by Weyerhaeuser. By 2011, there were about 88,000 registered tree farms covering 26 million acres.

The mechanization of farm and forest had a profound effect on American life. It made possible the rapid development of the frontier by farmers and ranchers who increasingly replaced human labor with technology. Innovation, both mechanical and biological, served national and worldwide markets for food produced thousands of miles away from consumers. It freed families in New York from the dreary routine of winter diets of potatoes, turnips, and salted meats, providing instead regular fresh fruit and meat hauled in from California and Texas. These technologies made possible tomato salads in February and fresh steaks in July.

At the same time, new agricultural technology made farmers (and urban consumers) dependent on these machines and the commercial networks that exploited them. Farmers were obliged to specialize; and in the long run, the independence of agriculturalists and the vitality of their communities declined. Consumers of mass-produced food no longer had contact with the soil or the rhythm of rural life. In the twentieth century, many Americans sought to regain this link to nature with home gardens and patronage of local farmers' markets. American success in systematically clearing forests created farmland (especially in the Northeast) and gave consumers relatively inexpensive houses and furniture. But that progress also caused erosion, and very quickly deforested whole regions without clear plans for conservation. Even though the negative effects of nineteenth-century mechanization have been partially reversed (in reforestation, for example), its ambiguous legacy remains today.

Suggested Readings

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8 Americans Confront a Mechanical World, 1780–1900

Americans have long seen themselves as a mechanical people who embraced technological innovation more readily than other nations burdened with longer histories and more customs. From the time of the first settlers, Americans have congratulated themselves for having escaped the privileged and leisurely ways of the European aristocracy and the tradition-bound misery of the Old World peasant. As we have seen, not only were nineteenth-century American workers far less likely to sabotage new machinery than were Europeans, but American employers were more quick to abandon an old technology for another more up-to-date one than were the Victorian British. Soon after independence, many Americans believed that technological progress would deliver humanity from drudgery, dependence on others, and dreary uniformity of life. In fact, so pervasive was the American infatuation with technology that Americans were slow to develop a critique of the impact of technology upon nature, work, and, more broadly, society and the human spirit. For a generation after the English poet William Blake condemned the 'dark Satanic mills' of England in 1804, American writers praised their own textile factories as models of human improvement for worker and consumer alike. Yet eventually Americans too came to question the benefits of the machine, though in ways sometimes different from the critiques of Europeans. Across the decades between 1780 and 1900, we see how Americans developed distinct ways of relating to the machine.

The American response to industrialism was governed by more than merely the Yankee habit of 'tinkering' and a commitment to material advancement at almost any cost. Americans shared preindustrial values with other peoples: Among these values were a love of rural life, praise for the 'moral' benefits of hard physical work, and suspicion of material 'luxury' as corrupting. None of these three values easily blended with industrialism's sometimes negative impact on nature, the dignity of work, and the simple life.

How did Americans deal with these changes and losses? They responded in different ways: From denial that traditional values were really threatened by technology, to physical or psychological withdrawal from the modern industrial world. More commonly, however, Americans found ways of adapting preindustrial ideals to a transformed world of cities, semi-automated work, and materialism. They preserved their pastoral values, cult of the dignity of labor, and glorification of plain living even as industrialism undermined these traditional goals.

In the 1840s, a few New England humanists and labor leaders challenged the notion that technological innovation was identical with America's destiny. Only toward the end of the century, however, did many Americans begin to question the fruits of technology. These Americans complained that ugly, dangerous cities replaced quiet villages; they lamented that work increasingly brought little joy and separated the machine tenders from the machine owners; these critics feared that industrialism was replacing the self-sufficiency and plain living of the past with dependence on and even addiction to machine-made goods. But even these American critics of technology often found a place for the machine in their ideal worlds: According to some of these thinkers, technology such as the automobile or electricity would preserve a rural culture by allowing urban workers to escape the city and nerve-racking labor to the leafy suburb or countryside. They were convinced that Americans could find ways of preserving the work ethic while accommodating affluence.

Pastoralism, the Work Ethic, Simplicity, and the Machine

Americans have long taken pride in their 'Virgin Land.' They lamented the intrusion of money and technology into rural life. As Jefferson saw it in 1785, "Those who labour in the earth are the chosen people of God …. Corruption of morals in the mass of cultivators is a phenomenon of which no age nor nation has furnished an example …. Let our work-shops remain in Europe."[1] This opinion resonated in American political life for another century, culminating in the populist protest of farmers against the power of banks and railroads in the 1890s. These ideas survived even though they did not slow the advance of industrialism.

One reason for the appeal of this agrarian myth was that it was accompanied by another idea—that the American wilderness had to be tamed and productive. The virgin soil was not to be raped; it was to be married to American labor and tools. The ideal was a 'middle landscape,' the blending of human reason, technology, and goods with nature. Early Americans glorified not the wilderness but the 'garden,' a neat farmhouse and barn surrounded by fields of corn and wheat, or even a gristmill peacefully placed next to a clear stream and a grove of trees.

To Jefferson, farmers were virtuous because they were presumably free of the grasping desires of the urban rich and the ignorance and dependence of the industrial poor. But he never embraced the idea of a permanently undeveloped America of self-sufficient agrarians. He agreed with his rival, Alexander Hamilton, that this course would be national suicide in a world where a county's power increasingly depended upon industrial prowess. In any case, the 'agrarian' Jefferson was as much an admirer of mechanical ingenuity as was the 'industrial' Hamilton. For Jefferson, the machine, when freed from 'feudal Europe' with its haughty aristocrats and cowering peasants, would liberate humanity from repetitive toil and arduous labor. Technology was wed to 'republican virtue,' for it was the handmaid of honest work and independence. American machines would produce simple American goods and free the new nation from the allure of foreign luxury. To Jefferson's generation, escape from the 'oppression' of hard work and want, through technology, went together with political liberty. Jefferson, of course, was primarily thinking of agricultural and domestic technology. He opposed only the large urban factory, which he believed created a chasm between the rich and the poor. However, a society of self-sufficient and roughly equal farmers could thrive, he believed, with 'American technology.' No matter how naive this seems from the vantage of today, Jefferson was optimistic that even the steam engine would not destroy 'nature's nation' and rural life (Figure 8.1).

A second cultural tradition that shaped American thinking about technology was the work ethic. This ideal descended from the Puritan belief that there was salvation in labor. This contrasted with traditional views. According to ancient philosophers like Aristotle, physical work was humiliating and suitable only for slaves. New England Puritans insisted that everyone's work was in service to God. Thus no one should waste 'God's time' in trivial pursuits or

Figure 8.1 The idealized Machine in the Garden: the old village waterwheel in a bucolic rural setting.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

idle speculation. As the Massachusetts pastor Increase Mather warned, "Every man's Eternity ... will be according to his improvement of time here."[2] Time was a loan from God—and God expected a return on the investment. Moreover, idleness only led to temptations of sex and other dangerous passions; it created spiritual unrest, what we might today call anxiety. Work ingrained habits of self-control and prudent preparation for an uncertain future. The work ethic was central to the thinking of many Americans, especially in the North.

Benjamin Franklin, a child of Puritans and himself a successful artisan, extolled the virtues of hard work and saving time in his *Poor Richard's Almanac:* "Sloth like Rust, consumes faster than Labour wears .... There will be sleeping enough in the Grave."[3] According to Franklin, methodical work and character were the keys to personal success, and he passed on these values to generations of success-bound Americans. This American horror of idleness amused and baffled European visitors (and often Southern American plantation owners). This attitude seemed to make work an end in itself rather than a means to pleasure.

According to many early Americans, work brought dignity and built 'character.' This might have led to a hostile reaction to mechanization that threatened manual work and traditional skills. But labor was not only its own reward; it brought material and other benefits. According to this common belief, no one would be a permanent wage worker—if they applied themselves. Eventually, they would gain autonomy and social status, and rise above manual labor—and dependence on the machines of work. Despite mechanization, many Americans did not feel that technology threatened their personal dignity and mobility won through individual effort.

The American work ethic was rooted in a preindustrial society of artisan masters and independent farmers. While Americans continued to embrace values of these craftspeople and farmers, they were also enamored by technological change and those who brought it. In part this was because many identified with the entrepreneur and inventor rather than the laborer. Nineteenth-century Americans often portrayed their inventors as perfect examples of the moral force of work—even when these innovators created machines that deskilled or displaced labor. In popular culture the inventors who built practical reapers or telegraphs were treated as morally superior to ivory-tower intellectuals or poets. Americans admired inventors when their labors paid off in fabulous personal wealth and power. Newspaper columnists never tired of telling the life stories of Thomas Edison or Henry Ford as models of industrial leadership. This was myth, for most captains of American industry—especially after the Civil War—were usually not inventive farmers' sons, but men born into at least modest wealth and with backgrounds in sales and management rather than invention. Still, many Americans believed that anyone could build a 'better mousetrap' and win admiration and wealth for the effort.

Americans' understanding of the 'Lowell System' of factory work clearly reveals how the traditional work ethic could survive in the face of technological change. Many believed that the American environment would 'purify' the 'dark satanic' textile mills of England. American visitors to Lowell's textile factories in the 1820s and 1830s were convinced that the 'mill girls' benefited from the character-building effects of steady, supervised labor. As we saw in Chapter 4, these model factories did not survive the 1840s. Still, many Americans clung to the notion that mechanized work was a teacher of frugality and diligence to the otherwise improvident poor. As late as the 1880s, Carroll Wright, a prominent New England expert on industrial labor, still argued that the mechanized factory was a moral force: It replaced the intermittent work of the old craft and putting-out system with the regularity of supervised labor. Other apologists argued that repetitive labor suited the weak-minded masses that were employed in the factory. Greater intellectual exertion would only confuse them. This was Henry Ford's rationale for the monotony of the assembly line in the 1910s. The work ethic and the idea that labor ennobled the individual, then, could survive industrialism, according to many Americans.

Along with this attachment to pastoralism and the work ethic was a third preindustrial value, the glorification of thrift and the simple life. Colonial Americans, even those who had attained a measure of wealth, contrasted their virtuous self-sufficiency and disdain of luxury for its own sake with the self-indulgence and corruption of the Old World aristocracy. Nineteenth-century presidential candidates bragged of being born in log cabins. This praise of simplicity and hostility to luxury cropped up again and again in popular stories about mountain men and western cowboys. But these values were accompanied by the common American quest for 'success' that often required adopting of new technology. And, success, of course, often led to luxury. Starting in a log cabin and learning the virtues of constraint and unadorned living did not mean that Americans were satisfied to remain poor. Praise for the simple life and its virtues sometimes made Americans rich and not so 'simple.' Without a doubt, many Americans were able to combine the traditional values of agrarianism, the work ethic, and simplicity with an optimism toward technology.

American Devotion to Technology and Inventors

American technological optimism thrived as the nation became more affluent. A perhaps extreme example of this optimism is John Etzler's *The Paradise within the Reach of All Men, without Labor, by Powers of Nature and Machinery* (1833). This book promised that mechanization, within ten years, would bring effortless, costless fulfillment of most human needs. This joyous embrace of an industrialism that benefited all sometimes overcame traditional scruples against personal 'luxury' and excessive comfort. For example, the minister Henry Bellows, in 1853, brushed aside these Puritan concerns by assuring his readers that "luxury is debilitating and demoralizing only when it is exclusive." American affluence benefited not just the rich, but everyone, and thus was not corrupt.[4] As long as access to the cornucopia of plenty was not restricted to the idle rich, it posed no moral problem. The old virtues of simplicity and self-denial, which had sustained artisans and farmers for centuries of scarcity, imperceptibly gave way to the new idea that Americans, as they became affluent, had an equal right to consume.

For many Americans, technological advance was the veritable fulfillment of a democratic age. In 1831, for example, while English authors like Thomas Carlyle were launching a full-scale attack on industrialism as the destroyer of community and soul, Americans refrained from such laments. Timothy Walker condemned as "idle, visionary, impractical" Carlyle's demand that we cultivate the spiritual and moral life as an antidote to mechanical thinking. Instead, Walker claimed, technology improved on nature by providing canals and railroads where rivers were lacking. Machines alone could free all of humanity from its age-old drudgery and give people the time and energy required to be creative or reflective. Critics of industrialism were only defending the old leisure class, whose culture and intellectual life depended on the animal-like labor of the masses. Once again, the problem with luxury was that it had been restricted to the few, not that it threatened the virtue of plain living. Technology, Walker and other Americans argued, could overthrow old tyrannies based on inherited wealth and mass ignorance. The railroad and telegraph overcame all barriers between peoples, and access to their powers would become available to all through mass education.

Victorian Americans valued useful ingenuity rather than high art. They often associated painting, sculpture, and architecture with the 'parasitical' European aristocracy. American art was best expressed in the simple and utilitarian beauty of the machine. A steam engine was a 'poem' embodied in metal. The inventor could not deceive the people the way that poets and painters did with their pretty words and sensuous images. The inventor became a kind of moral hero dedicated to hard work and the practical needs of the people. Edison was called a 'wizard,' but he was no mad scientist like the maker of Frankenstein (an English tale). He was a man with a fifth-grade education who, through tenacity and a practical mind, was able to solve the riddle of electric light, which had eluded educated foreigners. The practical, down-to-earth American inventor stood in contrast to the effete and elitist foreign artist and poet. American machines were often embellished with Victorian floral and geometric designs, but this only confirms the desire of their manufacturers to declare machines as the true American art, the creations of a democratic civilization.

Technology affirmed American ideals of progress and national greatness. Soon after its first appearance on the American landscape, the railroad became a powerful symbol of that progress. It was the machine that could 'annihilate' space and time. It overcame one of the greatest physical barriers of the new nation—the distance that separated producers and markets, friends and family. And, as a famous Currier and Ives print shows, the railroad symbolized the conquest of the West by the forces of American civilization. In that print, the locomotive departs the Eastern settlement for the vast open territory of the West and leaves in its smoke a pair of Indians on horseback. By the end of the nineteenth century, American proponents of technological progress argued that America's inventions were benevolently conquering the world. These technologies, rather than American armies, were making the United States a world power, soon to overcome the old empires of tyrants (Figure 8.2).

In their sheer variety, inventions—from stem-winding watches to suspension bridges—were the signposts of a century of progress. Who, asks Edward Byrn in 1896, would trade the comfortable rail carriage whisking its passengers along at fifty miles per hour for the "rickety, rumbling, dusty stagecoach" of a century earlier?[5] The sheer power of the machine became an object of contemplation, just as mountains and great waterfalls or even God had earlier inspired the imagination of people. This fascination with the power of human invention over nature expressed the extreme confidence of nineteenth-century Americans.

In this near-worship of the technological "sublime," the United States had no peers. Why? This new nation had no past glories or ideals to contemplate, as did Europe with its ancient ruins and medieval cathedrals. Instead, the American saw technological "progress as a kind of explosion" that suddenly transformed the primitive conditions of wilderness life into a wonder of abundance and comfort.[6] This sudden contrast between the wastes of uncultivated land and technologically advanced civilization was unprecedented in Europe, where material change was far slower. Settlers came to the new world, and American pioneers trekked across the frontier, realizing that they were

Figure 8.2 A famous Currier and Ives print, "Across the Continent" depicting the railroad's conquest of the West. Note the Indians 'eating' the dust and smoke of the locomotive.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

abandoning past civilization and its comforts—but they also expected soon to enjoy a "higher," more abundant life than they had left. And this, they well knew, depended upon the machine. Is it surprising that many Americans were grateful for technology?

Beginnings of an American Critique of the Machine

These hymns of praise for technology did not go unchallenged. Leading the critique from the 1840s were a group of romantic Americans led by Ralph Waldo Emerson and Henry David Thoreau. In his youth, Emerson shared the common conviction that factory work could train the "unruly masses." By the 1840s, however, he began to lose faith in the machine. The bland assumption that technology was the solution to all problems seemed to deny the need for individual moral vision and responsibility. His famous dictum of 1851 expressed this concern: "Things are in the saddle and ride mankind." In the hope of regaining a sense of personal integrity and imagination, Henry David Thoreau called for a return to the simple life of harmony with pristine nature. His *Walden, or Life in the Woods* (1854) glories in the undisturbed sounds of leaves and birds and the sight of sunlight playing on flowers and deep clear waters. In a critique of what he considered an obsessive quest for wealth, Thoreau advocated that we do more than "cut and trim the forest." We should contemplate undisturbed nature (as at Walden Pond) as an antidote to the industrializing city, where people "have become tools to their tools," living a soulless life of working at the machine and consuming stuff, without any real goals. The laborer, claimed Thoreau, "has no time to be anything but a machine" working to the unstoppable turns of the clock and gear.[7] Nathaniel Hawthorne's story "Celestial Railroad" mocks the cult of speed and ease that he believed had diverted Americans from the painstaking but uplifting pilgrimage through the Christian life.

However, even this romantic critique of industrial life was tempered by an appreciation of the beauty and power of the machine. In *Walden,* Thoreau concedes: "When I hear the iron horse make the hills echo with his snort like thunder … it seems as if the earth has got a race now worthy to inhabit it. If all were as it seems, and men made the elements their servants for noble ends!"[8] Thoreau seems to admit that machines were not really the problem; rather it was the ignoble goals of the people who owned them.

As we saw in Chapter 6 some industrial workers shared these doubts about the goodness of industrialism. Far from creating a new generation of American virtue, Lowell workers argued in the 1830s and 1840s, the mills were denying factory hands the time to think, pray, and otherwise become "virtuous." Rather than creating an industrious citizenry, the mills were creating a new aristocracy of factory owners as haughty and corrupt as those English whom the patriotic revolutionaries had defeated some fifty years earlier. Early American labor leaders like Seth Luther saw Lowell as the future Manchester of America with its deep chasm between capitalists and workers. Often the conditions of factory workers were compared with those of slaves. The wage earner sold his/her time to the machine just as much as the slave was sold to the plantation owner. For Luther, a remedy was to reduce the hours of the day required to be a 'wage slave.'

The more common response to industrialism, especially in the middle classes, was not to reduce work time but to promote Sabbatarianism. This religiously inspired movement demanded that the mechanical rhythms of railroads and factories be suspended on Sunday in hopes of preserving the natural and sacred time of traditional rural life and religion. But this hardly challenged industrial time during the other six days.

Reconciling Technology with Traditional American Values

In the 1840s the warnings and appeals of Thoreau and other reformers were hard for Americans to embrace. After all, most white Americans continued to work in small workshops and on their own farms. However, this changed after the Civil War. Whole industries were transformed quite suddenly. Within a decade after 1860, the artisan shoemaker was replaced by the machine operator working at the McKay Stitcher. Workshops employing 150 artisans were rare in 1850, but plants occupying 4,000 were common by 1900. Between 1860 and 1920, American manufacturing increased almost fourteen-fold (while the population merely tripled).

All this challenged traditional American values: Old pastoral ideas were threatened by the growth of industrial cities. Industrial work increasingly was a dead end and deadening. And the cornucopia of goods that flowed from these factories made a mockery of old ideas about the simple life. Earlier ways of reconciling these ideas with industry were no longer working.

From about 1880, some American thinkers decried the impact of city life on an America built on the culture of rural and small-town communities. Social and medical scientists began to claim that mechanized work in faceless cities was responsible for a long list of social ills. These included increased rates of suicide, crime, and divorce; an unwillingness of many people to accept regular work; stunted physical development of the young; and even a presumed lower average intelligence. Rapid uncontrolled technological change was destabilizing humanity, argued the psychologist George Beard. It was creating a race of increasingly enfeebled and anxious personalities. The steam engine and the telegraph that were supposed to relieve humanity of work, he argued, actually only increased the pace of work. Industrial noise, unlike the rhythmical and even melodious sounds of nature, was nerve-racking. The increasingly intense and impersonal workday, Beard noted, led Americans to repress necessary emotions. These were echoes of the old American pastoralism.

This growing discomfort with industrialism was expressed in a utopian novel of the Minnesota populist, Ignatius Donnelly. His *Caesar's Column* (1889) transports the reader one hundred years into the future to New York

City in 1988. There the hero Gabriel Weltstein from the countryside discovers how elegant shopping arcades conceal an underworld inhabited by a numbed proletariat ruled by a despotic oligarchy of the rich. The city had become a hell for the many who made possible a decadent heaven for the few. A terrorist 'Brotherhood of Destruction,' led by Caesar Lomellini, plots to overthrow the plutocracy. The resulting anarchistic violence ends in the destruction of the city, and the hero flees the chaos to find a harmonious agrarian society in Africa, free from the temptations of urban and industrial life.

While some looked to the past or future, most American sought solutions to the problem of the industrial city in the present. They tried to adjust to technological change. These Americans found ways to compromise between their traditional ideals and the new technology. One example is the common attempt (at first, of the rich) to regain the 'garden'—that is, traditional pastoral values. The answer was not by returning to the farm and village, but by taking a train or car ride from the city to the country home or leafy suburb. There, the affluent—often refugees from the industrial pollution that they had helped to create—would find the space for a house surrounded by lawn. The suburban home was to be isolated from the mechanical rhythms of the city and from unnecessary contact with neighbors. This late Victorian ideal was not the wildness of the forest, much less the smelly, muddy farmyard; rather, it was a neat home surrounded by ornamental trees and manicured gardens built on a winding road. The ideal country or suburban home was to be set back but be visible from the street. The parklike landscaping in the front both displayed the owner's taste and provided privacy. The rich of nineteenth-century Paris and other European cities built a leisure style around the restaurant, theater, and gallery, and lived in luxurious apartments along tree-lined boulevards. But the Anglo-American rich gradually abandoned the city to the poor and to business for the leafy suburb and individual houses on one third acre lots.

Ironically, this escape from the consequences of technology depended upon new transportation technology. From as early as 1829, horse-drawn 'omnibuses' served outlying regions of Philadelphia and other cities, often traveling over fast wood-plank roads. In the 1850s, streetcars (on rails, but still horse-powered) offered even faster commuting; soon these were replaced by steam railroads that could deliver the urban businessman to new homes in formerly sleepy outlying villages. Mid-nineteenth-century model suburbs like New Jersey's Llewellyn Park and Chicago's Riverside set the pace. Wealthy districts in Westchester County, New York, and in Chestnut Hill near Philadelphia, radiated from train stations, protected in their isolation from other communities by farmland. Meanwhile, older districts of inner cities or whole parts of town (like Chicago's south side) were destined to become industrial and working-class residential districts and often slums. In the late nineteenth-century suburb, affluent Americans had found a way of combining the traditional longing for the countryside with urban technology in their daily escape from work in the city to home in the suburbs (Figure 8.3).

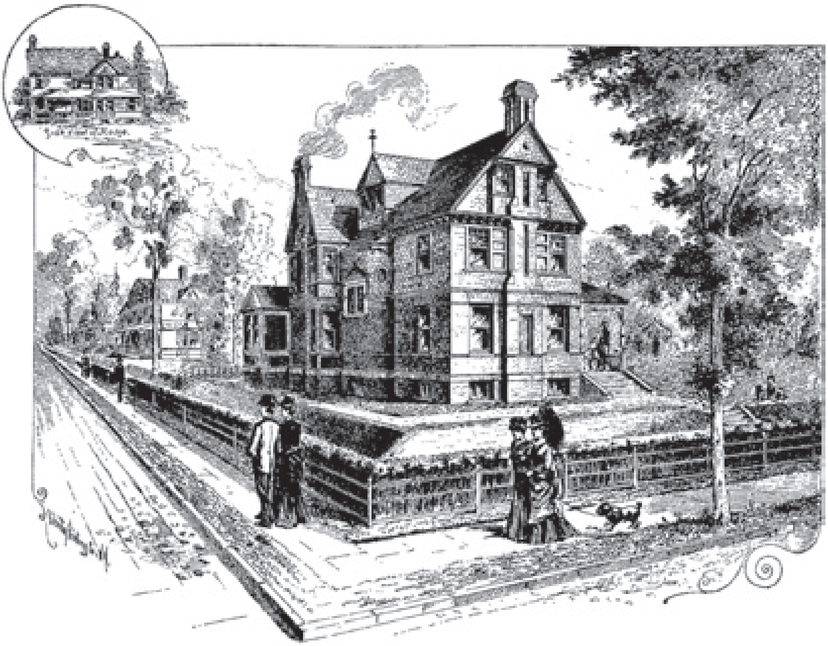

Figure 8.3 A drawing from a famous collection of suburban homes for the wealthy. Notice the manicured setting in nature, far from the crowded industrial city.

Credit: *New York Cooperative Building Plan Association, Shoppell's Modern Homes, 1904, 16.*

By the 1870s, American thinkers were also beginning to reassess the notion that industrialization was consistent with the gospel of hard individual work. As labor became machine-driven repetition, so also it seemed to offer less chance for advancement into self-employment. Thus, the promised rewards of hard work appeared to be undermined. Mechanized labor seemed to remove all the 'moral' elements of work—the dignity of labor, individual initiative, and the social bonding of the old workplaces. By the 1890s, educated middle-class reformers were beginning to reassess the assumptions of their fathers about the moral value of factory work. Social investigators and journalists like Walter Wyckoff (who actually worked in factories) found industrial work to be demoralizing, monotonous, and exhausting. Work at the machine seemed to lose its ennobling character, its moral capacity to subdue passions, defer needs, and give honor and dignity to the laborer.

One response to this 'degeneracy' of work was to look backward to a once golden age when self-directed individuals matched hard work with intelligence to produce a virtuous society. New England writers like Henry Adams and Charles Eliot Norton glorified the preindustrial 'harmonies' of medieval craft guilds and village life. The 'Arts and Crafts' movement of the late 1890s attempted to restore the dignity and skills of the traditional crafts. Leaders of this movement set up artisan workshops in an attempt to recreate the work world of medieval England in which, supposedly, crafts were an art, and work and life were integrated. These scattered efforts had little practical impact on modern factory conditions, but they did reflect an attempt to restore the traditional work ethic.

More common was the perspective of the social worker Jane Addams of Chicago, who hoped somehow to bring 'joy' back to work in the modern setting. She stressed the need to inculcate new attitudes in work—by helping production workers understand how they fit into the wider industrial picture. In the 1890s she opened a labor museum, hoping to give working class visitors a feel for the history of modern industrialism. She advocated that teamwork be stressed in vocational training and that employers show their respect for workers by providing lunchrooms and opportunities for input. By 1900, reformers hoped that vocational placement testing would screen out the potentially maladjusted worker. Those concerned about the dignity of work offered a myriad of palliatives in response to the reality of the permanent wage earner; these included cooperative worker-owned factories in the 1870s and profit-sharing schemes in the 1880s. Both ideas fell victim to repeated recessions, and skepticism from labor and capital alike.

This reassessment of industrial labor went beyond nostalgia and attempts to bring dignity back to work. A new generation of intellectuals looked more kindly toward leisure as a positive alternative to work. Time free from work had been understood as a threat to diligence. But with the approach of the end of economic scarcity, leisure seemed now to offer an opportunity for workers to regain psychological and social health with time free from the rigors of industrial work.

Leading this movement, quite naturally, were workers. For many of them, time away from the job was the only way of regaining the traditional value of independence and personal dignity. Sometimes this quest for free time was organized: The demand for a ten-hour workday in the 1840s was followed after the Civil War by the eight-hour movement. The nationwide strike in 1886 for the eight-hour workday captured the imaginations of hundreds of thousands of American workers. A popular labor song of the day praised the freedom of leisure:

> We are tired of toil for naught.
> With but bare enough to live upon
> And never an hour for thought
> We want to feel the sunshine,
> And we want to smell the flowers.
> We are sure that God has willed it.
> And we mean to have eight hours. …
> Eight hours for work,
> Eight hours for rest,
> Eight hours for what we will![9]

These ideas were anathema to most upper-middle-class observers, who saw them as a threat to public morality and industrial growth. Yet these same affluent Americans were taking advantage of their newfound economic security to relax. In the 1850s, Henry Ward Beecher, a descendant from an old Puritan family of preachers, taught the virtue of recreation and escape from the feverish pace of industrial life in summer vacations. Still, he exhorted the young and poor to constant labor. By the 1880s, however, some thinkers were beginning to abandon this double standard and recognize the special problems of industrial labor. For example, biologists claimed that mechanization was causing a general exhaustion of the 'human motor.' Industrial fatigue had to be reduced by shortening the workday and by regulating the pace and methods of work. Close monotonous work, even in clean factories with 'labor saving' machinery, argued Josephine Goldmark in 1912, was at least as fatiguing as heavy work. Only regular rest and recreation could overcome the damage done by the atrophy of muscle groups and stress to eyes and fingers inherent in industrial work.

This new attitude toward leisure took many forms. One expression, by about 1900, was an increasing acceptance of annual vacations (at least for white-collar workers) and a half-Saturday 'weekend' for the skilled workforce. About the same time, Henry Curtis, a leader of the Playground Association, argued that industrialism destroyed human vitality. This energy could be restored only in sports and games. Many, including Theodore Roosevelt, argued that organized sport could train youth to sober habits of work and cooperation. Leisure was to be both an escape from and preparation for industrial life.

Along with this reassessment of the work ethic (and more positive assessment of leisure) came new ideas about another American value—simplicity (and its opposite luxury). The old virtue of thrift and 'making do' with what you have, was beginning to give way to a new attitude. From the 1870s on, we hear arguments that Americans should consume more. In part, this was prompted by concern that productivity was outstripping the ability of Americans to sell goods. In the first two decades of the twentieth century, economist Simon Patten insisted that a new civilization of plenty required a new morality of spending and enjoyment. It meant also a de-emphasis on saving and endless toil. Like many of his generation, Patten doubted that mechanized work could build character. Instead, a consumer culture could expose working people to the 'vitality' missing in their work-a-day lives. As basic needs were met, wage earners would move away from the deadening pleasures of the saloon and toward higher cultural aspirations. Working people, Patten and others argued, would eventually join the more affluent in sharing the joys of suburban life. This may seem naive to readers today. Still, Patten's argument flowed quite naturally from an attempt to reconcile industrial affluence with traditional cultural values. It assured Americans who retained a faith in the old ideals of simplicity and worried about the corrupting effects of affluence on the masses that they had little to worry about. Patten advocated not aristocratic 'luxury' but a 'democratic' sharing of the benefits of industrial life—and this would lead not to degradation, but to cultural uplift.

Americans have long loved their machines. This affection was perhaps an inevitable offspring of an ambitious and individualistic nation cutting its way through a wilderness. But Americans were also obliged to adjust their love of technology to equally held values of pastoralism, the traditional work ethic, and thrift. Solutions were many and contradictory. The dominating ones are still with us and are built into our suburban consumer culture in many subtle ways.

Notes

1 Thomas Jefferson, *Notes on Virginia*, query XIX, cited in Leo Marx, *The Machine in the Garden* (New York: Oxford University Press, 1967), 25.
2 Increase Mather, *Testimony Against Profane Customs* (Charlottesville, VA: University Press of Virginia, 1953), 31.
3 Benjamin Franklin, *Benjamin Franklin: The Autobiography and Selections from His Other Writing* (New York: Liberal Arts Press, 1952), 85–89 and 231.
4 Henry Bellows, *The Moral Significance of the Crystal Palace* (New York, 1853), 16, cited in John Kasson, *Civilizing the Machine: Technology and Republican Values in America, 1776–1900* (New York: Hill and Wang, 1976), 40.
5 Edward Byrn, "The Progress of Invention during the Past Fifty Years," in *Scientific American, 75* (July 25,1896): 82.
6 Marx, *Machine,* 203.
7 H.D. Thoreau, "Paradise to Be Regained," in *United States Magazine* (November 1843): 454, cited in Thomas Hughes, *Changing Attitudes toward Technology* (New York: Harper and Row, 1967), 91.
8 H.D. Thoreau, *Walden; and Civil Disobedience* (New York: Penguin, 1983), 161.
9 Cited in notes to phonograph recording, *The Hand that Holds the Bread* (New World Records, NW 267,1978).

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9 The Second Industrial Revolution

One must always be careful not to abuse the word 'revolution.' Technological revolutions take longer than political revolutions, but they may have a more significant impact on society. The First Industrial Revolution ushered in the modern era of the factory and rapid technological change. Its technology steadily improved throughout the nineteenth century. Late in that century, a new series of innovations emerged that would dominate industrial society through the twentieth century. Three critical breakthroughs constitute the Second Industrial Revolution: The internal combustion engine, the harnessing of electricity, and a radical change in the understanding and application of chemistry. These developments, along with improvements in steelmaking, propelled Americans fully into an industrial age. Indeed, virtually all twentieth-century innovation depended on at least one of these three breakthroughs.

The Second Industrial Revolution was naturally related to the first. The growing textile industry encouraged most nineteenth-century chemical research, which focused on dyes, bleaches, and cleaning agents. Iron producers struggled to understand the chemical reactions involved in improving iron and making cheaper steel. The railroad, by uncovering the potential demand for personal travel, greatly encouraged the development of the automobile. And it was the railroad, too, that provided the first practical experience with electricity, through the telegraph.

These three breakthroughs, however, were themselves revolutionary changes. Not only did they introduce most of the goods that we take for granted today, but they were also products of very different processes of invention than were the innovations of the First Industrial Revolution. Those earlier discoveries were still primarily the result of trial-and-error tinkering. The Second Industrial Revolution was much more a product of science and organized research. The third quarter of the nineteenth century was a period of unprecedented advance in scientific understanding: Louis Pasteur, Charles Darwin, Gregor Mendel (though his discoveries in genetics would be ignored for decades), August Kekule (the discovery of the benzene molecule), Dmitry Mendeleyev (the periodic table), James Clerk Maxwell (electromagnetic theory), and J. Willard Gibbs (thermodynamics). Itself a response to technological advance, increased scientific understanding naturally stimulated further technological inquiry.

By focusing in turn on distinct technological trajectories, we can too easily lose sight of the interdependence of technological evolution. Electrification, chemical understanding, and internal-combustion developed in mutually reinforcing ways over the next decades. Automobile spark plugs and electrical insulation were fashioned of plastic. The auto industry also depended on advances in oil refining and rubber manufacture. Many chemical processes were possible only with electricity. Most complex modern products owe their existence to more than one of the three elements of the Second Industrial Revolution.

The Age of Steel

In a way, steel does not belong in a discussion of the Second Industrial Revolution, for the late-nineteenth-century advances in steelmaking were much more clearly grounded in the First Industrial Revolution. Advances in steelmaking likely contributed more to science than they borrowed from it. New developments in steelmaking, however, predated only slightly the advances in electricity, chemicals, and internal combustion. Moreover, cheap steel made possible the mass production of automobiles and home appliances (wrought iron would have been too brittle for these uses). The later developments in the steel industry, and especially the alloy steels—combining iron with small amounts of other elements—were closely tied to developments in these other three sectors.

Throughout the first half of the nineteenth century, steel remained expensive. The small-scale production of steel in clay pots continued. Its use was thus limited to the military or small pieces in watches or knife blades. Yet its advantages were evident to all, and innovators naturally turned their thoughts to the possibility of producing steel on a large scale. Before mid-century, it was known that pig iron had a 4 percent carbon content, wrought iron 0 percent, and steel an intermediate 2 percent. Nevertheless, steel manufacturers struggled to achieve the desired 2 percent and found that techniques often worked better with some ores than others. Scientists were thus encouraged in their efforts to determine the exact chemical composition of different ores, and the chemical reactions that occurred in iron- and steelmaking.

In 1856, Henry Bessemer in Britain developed a seemingly simple solution to the problem of steelmaking. Rather than heating the pig iron in the usual manner, such that the exterior heated before the interior and thus carbon content was not the same throughout, he proposed blasting hot air through molten metal. He realized that the heat produced by the chemical reaction (of carbon with oxygen) would keep the metal molten. At the same time, excess carbon was removed by reacting with oxygen. A process that had taken days now took less than an hour. The output was not only much less expensive—less than twice the cost of wrought iron—but of high quality. Still, technical difficulties, coupled with the hostility of wrought iron producers, slowed diffusion somewhat.

The next development in steelmaking was the Siemens-Martin open-hearth process. This achieved higher temperatures by using waste gases to reheat interior bricks (similar methods were employed to obtain high temperatures outside of iron manufacture). These bricks served the same purpose as Bessemer's blasts of hot air; they heated the metal evenly so that half the carbon could be oxidized throughout. Although experiments were undertaken through the 1860s in Birmingham, England, the commercialization of the process began in the 1870s.

Both of these processes worked poorly on ores with a high phosphorus content. Britain and the United States were fortunate in having non-phosphoric ore deposits. Nevertheless, it was in Britain that the first successful technique for making steel from phosphoric ores was developed. Moreover, although the application of chemical theory to steelmaking had advanced considerably in the decades since Bessemer, this solution would come from the hands of an amateur with no scientific training, Sidney Gilchrist Thomas. This was the last significant advance in steelmaking of which that could be said. It had long been established that the addition of limestone to the molten ore would induce a reaction with the phosphorus, which could then be drawn off in slag. The solution involved, in addition to the limestone, the lining of the bricks in the furnace so that they would not be eaten away and thus release phosphorus back into the metal. Developed in 1879, the technique was quickly snapped up by producers in France and Germany. The British advantage in steel production was gone forever.

Output figures give some idea of the revolutionary impact of these three innovations in steelmaking. Before Bessemer, Western European annual steel output was barely 100,000 tons. On the eve of World War I, it was well over 30 million tons. By that time, steel had superseded wrought iron in almost all uses. In the United States, the presence of abundant supplies of nonphosphoric ore in the Great Lakes region accelerated the process; canals and railroads opened up this orefield in the late 1860s. Annual steel output of 70,000 tons in 1870 had expanded to 1.25 million tons a decade later, over 10 million in 1900, and 26.1 million in 1910.

Andrew Carnegie was one of the first Americans to see the possibilities of these European developments. He traveled to Europe and brought back engineers familiar with the new processes in order to transplant these techniques to American conditions. Not surprisingly, numerous adjustments were necessary. He was the first steelmaker in America to employ a chemist, and he believed that this gave him a decisive advantage over competitors. And he refitted his plants to deal with the evolving market for steel, from railroad rails to structural steel for construction, to sheets for industrial machinery and automobiles.

Following the advent of the Bessemer process, the US steel industry produced a series of critical improvements. Furnaces steadily expanded in size. Labor-intensive activities such as material handling were mechanized. From 1887, steelmakers moved toward continuous processing, whereby materials moved continuously from one process to the next: This both lowered the cost and enhanced the homogeneity of the final output. Furnace linings were improved, and walls were inclined to enhance heat reflection. Later, in the 1920s, instruments to regulate temperature and pressure were introduced.

Electrolytic methods (i.e., the passing of an electric current through a solution) allowed much cheaper manufacture of aluminum from the late 1880s. Manganese, tungsten, chromium, and molybdenum (elements unknown just decades before) could, in turn, be produced in pure form by reacting with aluminum. These were essential to the development of steel alloys of unprecedented toughness, heat resistance, and hardness. Cheaper steel and specialist alloys transformed American industry, making possible more durable machine tools and more complex products than had ever been possible before. Chromium and tungsten alloys were common in machine tools in the late nineteenth century, while the navy used nickel alloys for ship armor. The automobile industry needed steels that could handle a variety of stresses: First vanadium, and then chromium and molybdenum answered these needs. The electric furnace, in which heating by electricity meant that molten metals no longer reacted with the air, allowed the production of more uniform alloy steels; it was invented in Europe in the first decade of the twentieth century and adopted soon after that in the United States.

Notably, the technology used in steelmaking at the dawn of the twenty-first century would seem familiar to the engineer of the 1920s. Electric furnaces would become larger and more efficient over the course of the twentieth century (and would come to rely on scrap metal for as much as half of their input), and would replace open hearths entirely by 1991; some furnaces based on Bessemer technology would survive in the manufacture of basic steel. Continuous cooling would allow electric furnaces to adjust alloy composition precisely. As transport costs fell, steel mills came to specialize in one output, and 'mini-mills' largely replaced the vast integrated steel processing centers, especially for very specialized alloy steels for high-tech uses. Nevertheless, the steel industry of 1920, and even of 1880, looked more like the steel industry of 2000 than like the steel industry of 1850.

The Miracle of Electricity

In 1821, the Englishman Michael Faraday had discovered electromagnetic induction, whereby a rotating magnet induced an electric current in a copper wire. For the first time, it was possible to generate electricity mechanically. Electricity was used in communications—the telegraph, and later the telephone—and in electroplating precious metals, where the savings in expensive raw materials justified the cost of electricity production. For a half-century, however, practical techniques of electric power production were so inefficient that electricity in most applications could not compete with other energy sources. That is, while any power source could set a magnet spinning—including waterwheels or steam engines—the amount of electrical power generated was small relative to the power that could be produced directly by the same flow of water or steam.

The telegraph itself had a revolutionary impact on people's conception of space. Samuel Morse responded to a request from the American government for superior methods of communication and would after six years of research receive a subsidy of $30,000 for a telegraph line between Baltimore and Washington DC in 1844. Messages were transmitted in Morse Code, a set of short and long clicks that signaled the letters of the alphabet. Telegraph lines were soon built across the continent, often following railroad lines. Messages that had previously taken hours or days to transmit could now be sent in minutes (though messages were often then carried on foot or later by bicycle from the telegraph operator to recipient). With the development of the first successful cable between Newfoundland and Ireland in 1866, messages could also pass quickly between the United States and Europe. A series of technical innovations allowed multiple signals to be transmitted simultaneously. Still, telegraph messages were expensive in the United States and thus used primarily by business and the rich. The broader population might send occasional telegrams announcing births or deaths. They also benefitted indirectly as news media used the telegraph to report on events happening at a great distance. The telegraph thus served to connect distant communities. It required, in turn, a large body of technicians who needed some rudimentary knowledge of electricity and needed to be able to measure electric currents: They could not solely rely on mechanical skills. One company, Western Union, came to dominate the national telegraph network by the 1860s, inspiring efforts at government regulation—but only rarely calls for nationalization as in most of Europe.

Science would facilitate a dramatic reduction in the cost of electricity. In 1856, James Clerk Maxwell provided the first mathematical theory of electromagnetic induction. As a result, innovators had a much firmer basis on which to experiment with ways of generating more electricity from a given amount of magnetic spin. Over the next decades, the design of armatures (the iron frameworks wound with copper wire, fixed between the poles of a magnet) was much improved. As well, electromagnets (coils of magnetic material, such as soft iron, inside coils of wire) were employed to produce a strong magnetic field when a current passed through the wire.

Two interdependent advances occurred in the 1870s. Improved dynamos for translating the mechanical energy of the rotating magnet to electrical power in turn stimulated the development of the lightbulb. For decades, the lightbulb would remain the primary source of demand for electricity. Its improvement would, in turn, encourage a gradual process of advance in electricity generation.

Some of the potential of electric lighting had been illustrated in the 1850s by the development of the carbon arc lamp for use in lighthouses. The market for home and office lighting was clear: Gas companies had been serving it for decades, and it was evident that consumers would prefer a brighter, cleaner light. Thomas Edison produced a commercially viable lightbulb in 1879; he was able to synthesize numerous advances made in the previous two decades, particularly the development of vacuum pumps and filaments of better types and shape (see Chapter 10). He not only developed the first successful lightbulb but also a whole system of electricity generation and measurement to go along with it. The daunting complexities of electrification were such that it was the first American industry in which organized research laboratories came to dominate the innovative process. Edison blazed the trail that others were to follow (Figure 9.1).

With electric lighting in the forefront, electricity was increasingly applied to areas well beyond illumination. In the late 1880s, 180 cities introduced electric streetcars. With the development of an efficient electric motor came a stream of machines for home, office, and factory (see Chapters 12 and 13). Electricity, from the 1880s, was also applied directly in the production of chemicals and steel. This widening range of the uses of electricity led to decreased costs of production. Electric generation facilities were expensive to construct. As long as lighting remained the primary market, this capacity was only utilized a few hours a day, in the evening. Batteries of the time were not an efficient method for storing electricity. The new markets in urban transport, electric machines and appliances, and industrial processes drew electric power at different times of the day. As regional power systems developed in the United States, the advantages of both large-scale generation and serving diverse markets could be passed on to consumers.

Many innovations further decreased the cost of electricity to users. Cables and insulation were improved. Switches, fuses, and lamp sockets were refined. The humble lightbulb itself—filament, circuitry, and glass casing—was the subject of much innovative effort, which caused the cost of lighting to fall to a fraction of its former level. Mainly as a result of innovations in generation, transmission, and lighting technology, lightbulb use would increase sixteen-fold between 1910 and 1930.

Chemistry and its Applications

In the case of both electricity and internal combustion, we can point to a handful of innovations in the late nineteenth century that ushered in a new era. In the case of chemicals, we must speak instead of a dramatic expansion in both the output and range of chemical products. These transformations reflected a substantially increased understanding of chemical science. They, in turn, set the stage for the modern chemical industry, which produces thousands of distinct products (ranging from basic chemicals to plastics,

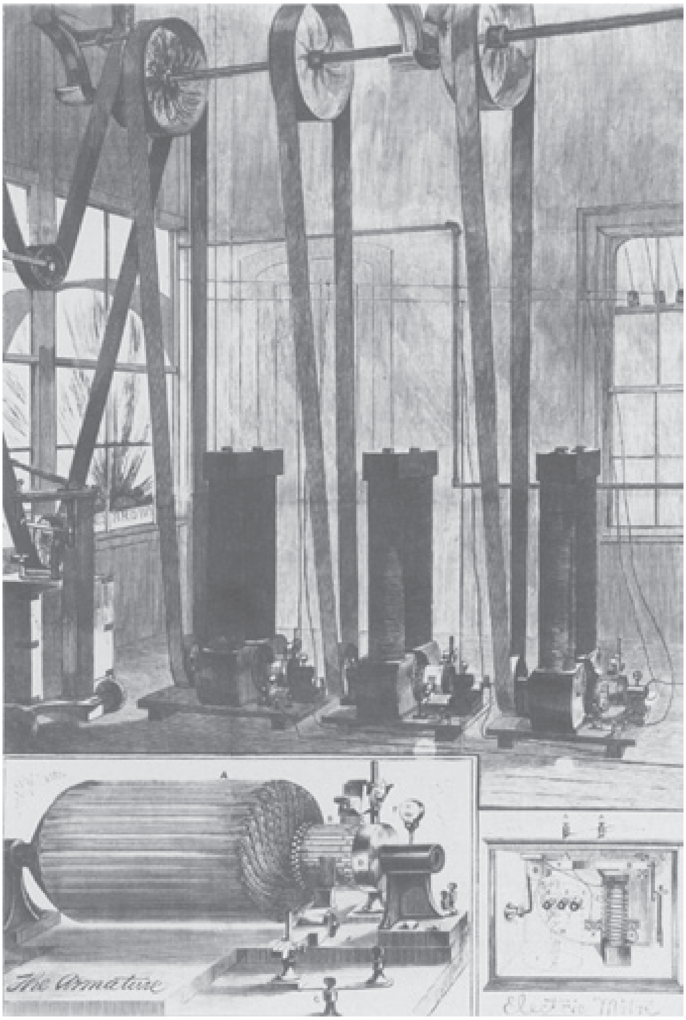

Figure 9.1 Electric power generation, 1880: Steam power turns the belts, which spin magnets, which induce currents in the wire. This drawing originally appeared in *Harper's Weekly*.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

synthetic fibers, dyes, and pharmaceuticals), constitutes 10 percent of US manufacturing output, and provides critical inputs to almost all of American manufacturing.

Advances in dyestuffs during the First Industrial Revolution were mainly derived from trial-and-error experimentation. Although technological progress was sluggish due to limited scientific understanding, a great deal of empirical knowledge was gained. This knowledge of dyestuffs would be the base from which most later developments in chemicals, including pharmaceuticals, would proceed. Moreover, these experiments provided a significant impetus to and source of data for scientific inquiry.

From the beginning of the nineteenth century, John Dalton applied atomic theory to chemistry; this established that elements combine in a particular numerical proportion (e.g. H_20). If two elements form more than one compound, these must also be in numeric proportion: There is twice the oxygen/carbon ratio in carbonic acid, for example, as in carbonic oxide. Although measuring these relationships was not possible at the time, chemical equations were of considerable use in understanding reactions. By midcentury almost all industrial processes could be understood in terms of chemical equations. Extraneous materials were then identified. Optimal temperature and pressure were established empirically. Later in the century, it became possible to determine the atomic weight of elements, and thus the formulae for almost all important substances.

In 1860, valency theory showed that atoms of a particular element always bond with a certain number of other atoms (e.g., the all-important carbon atom always bonds with four other atoms), and established the range of possible chemical compounds. Scientific understanding of the laws of thermodynamics (i.e., the relationship between heat and other forms of energy) and of the role of catalysts—substances that encourage a chemical reaction without partaking of it—around the turn of the century further aided technological innovation.

Organic chemistry is a term that refers to the analysis of living organisms, but in practice it means the study of compounds of carbon. These compounds are the key to such modern products as synthetic fibers, plastics, and antibiotics. Organic chemistry scarcely existed before the mid-nineteenth century. Only then did Claude Louis Berthollet establish that organic compounds could be synthesized. In general, precise conditions of temperature and pressure were necessary for successful reactions. Thus, progress would have been slow at best if only trial-and-error experimentation were possible. The primary focus of organic chemistry for decades was the synthesis of dyestuffs such as indigo (a blue dye made from plants) and madder (a red dye made from roots), which had previously been obtained from expensive natural products. Although the first synthetic dye, mauveine, was developed by William Perkin in Britain in 1856, his efforts were based on research on organic chemicals by German scientists. German chemical firms then established industrial research laboratories that would be the site of most developments in dyestuffs, and organic chemicals in general, until the end of the century. Whereas in 1870 there were only 15,000 known organic compounds, by 1910 there were 150,000.

Dyestuffs have the desirable property of adhering to certain other substances (the textiles to be dyed) but not reacting with others (and thus not fading with cleaning). This same general property of selectivity must be possessed by pharmaceuticals if they are to attack disease without killing the host. Drug research was thus one natural outgrowth of dyestuff research. So also was the effort to make both synthetic fibers and plastics that would be superior to natural products. The first plastic (a substance that takes a shape under high temperature that it maintains when cooled) was celluloid.[1] It was produced in 1869, and found uses in billiard balls, combs, and somewhat later, movie film. Bakelite, the first successful non-cellulose based (and thus fully synthetic) plastic, was marketed successfully from 1909. Its producers advertised that it had a thousand uses: It not only replaced wood, stone, and steel in many applications but could do many things that natural materials could not. Other early plastics served in car parts and as electrical insulation. In the late 1920s, it became possible to produce brightly colored plastics: This opened new markets in, for example, tableware and packaging.[2] Although the role that these early plastics played in the development of complex products was significant, problems with production and with flammability severely limited output until the 1930s. Nevertheless, some were already hailing the dawn of the Plastics Age in the late 1930s: Impressed by the 'magical' ability of plastics to create something out of nothing, they predicted a bright future free of want and (more accurately) rust and sharp edges.

Even though the first fully synthetic fiber did not emerge until the 1930s, a partially synthetic fiber based on the plant material cellulose was created in France between 1891–1892. Rayon was formed by treating wood pulp (and occasionally other plant material as well) with caustic soda and other chemicals, and then drawing the resulting substance out to create fibers. Production of rayon had been insignificant before demand was boosted precipitously by World War I. Thereafter, a steady stream of process improvements caused annual rayon production to rise to almost 200,000 tons by the end of the 1920s, and thus pose a serious threat to the long-dominant cotton industry, across markets as diverse as hosiery and tire cord (Figure 9.2).

Valency theory (described earlier) greatly facilitated the manipulation of organic chemicals, primarily due to the bonding behavior of carbon, hydrogen, and oxygen. It proved frustratingly insufficient for most inorganic chemicals, however. Reactions involving those would only be understood once it was appreciated that molecules bore an electric charge, and positively charged molecules would only bond with negatively charged molecules. Although ionic theory did not appear in most textbooks until the 1920s, it had emerged in the 1880s and became widely accepted in the 1890s. Here again, technological and scientific advances were mutually reinforcing. Electricity had been applied to electroplating for decades, and to copper refining from the 1860s (with electric wiring in turn providing the largest market for copper). Ionic theory finally explained why passing an electric current through solutions encouraged chemical reaction—substances with a positive charge would then bond with those carrying a negative charge—and predicted the optimal conditions for doing so. As costs of generating electricity fell in the late nineteenth century, electrolysis was used to manufacture aluminum, chlorine, alkali (for fertilizer), caustic soda, chlorates, hydrogen, and hydrogen peroxide.

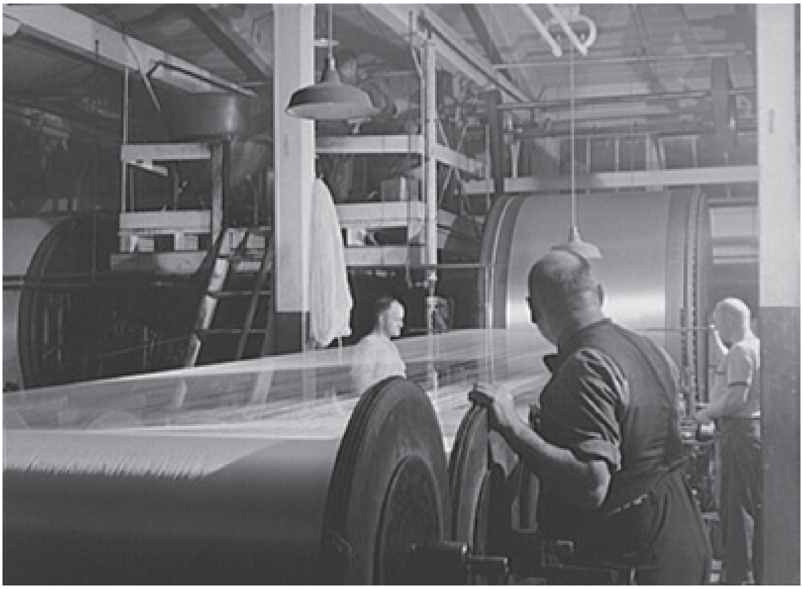

Figure 9.2 Preparing rayon thread at the Denomah Mills, Taftville, Connecticut, 1940s.
Credit: *Courtesy of the Library of Congress, Prints and Photographs Division.*

We have sketched only a few of the most important developments in the chemicals industry in the late nineteenth and early twentieth centuries. That industry came to be characterized by massive plants using sophisticated machinery to produce both new and old products at previously unimagined prices. After 1930, the range of products becomes infinitely more complex (see Chapter 19). Indeed, there are hardly any modern products that have not been affected by some chemical manipulation.

The American chemicals industry grew rapidly from 1860, and especially from 1900. It relied heavily on licenses to use German technology but gained access to German patents after World War I. American chemicals firms significantly expanded their research establishments after that. Lacking a long history of dyestuff research, they were slow to succeed in pharmaceuticals, but they would soon become leaders in plastics and synthetic fibers. American firms benefited from access to raw materials, especially after petroleum replaced coal as the basic building block of organic chemistry in the interwar period (the American chemicals industry then benefited from advances in petroleum refining encouraged by the American automobile industry). The American industry—perhaps because it operated on a large scale—was also the first to apply chemical engineering: It was thus better able to scale up laboratory discoveries to commercial production, and also to combine different processes in order to create new compounds. The critical insight here was that every chemical manufacture involves a few steps, such as mixing, pulverizing, heating, roasting, or precipitating. Rather than seeing the production of each chemical as unique, chemical engineering built up a scientific understanding of each step that could then be applied to the manufacture of any chemical. These advances in chemical engineering thus provided a further incentive to the development of new chemicals.

Internal Combustion

By the late 1880s, the technological potential of the steam engine had largely been exhausted. The last significant development was the large-scale steam turbine of 1884 for use in the production of electricity. Because internal combustion would have its most dramatic impact in the realm of transport, it might seem logical that it was developed to that end. The railroad had provided clear evidence of the market for personal transportation. So did the bicycle; there would be millions of these on the road before the automobile (and most early auto manufacturers had previously made bikes). However, internal combustion was initially designed to allow factory managers to overcome the mass of belting and dirt associated with the steam engine.

The principle of internal combustion is quite simple. An explosion in a confined space causes expanding gases to push on a piston with much greater force than the expansive power of steam could ever achieve. In a sense, the gun is a basic internal combustion engine. That explosions occurring at regular intervals might drive an engine was suggested as early as the seventeenth century when Christiaan Huygens had constructed such a device. The fuel he used was gunpowder itself, and this alone doomed his machine to have no practical application. (It is worth noting, however, that this first internal combustion engine predates the first steam engine.) Efficient internal combustion required both greater engineering precision and the development of superior fuels. These would not come together until the second half of the nineteenth century.

In 1859 Etienne Lenoir of Belgium used a mixture of coal gas and air to power the first workable internal combustion engine. He did not compress the gas before ignition, and thus his engine was very inefficient. Numerous engineers, however, immediately set to work to improve on his efforts. In 1862 Alphonse Beau de Rochas of France introduced the four-stroke engine, which has become standard, but his engine also had no commercial application. Nikolaus Otto of Germany developed a similar engine in 1876, but one in which the gas was compressed before combustion. This increased engine efficiency enough that tens of thousands of the machines were in use around the world within a few years. They had considerable advantages over steam engines. They were cleaner, and the fuel used—coal gas—could often be obtained at low cost as a byproduct of other industrial processes. They could be started and stopped more easily than steam and could run at half speed (which the steam engine could not). Finally, they required less labor to operate (Figure 9.3).

Coal gas had important drawbacks. First, it was suited only to the stationary engine, for the engine had to be connected to a large fuel tank. Second, it was suited only to relatively low-speed engines. An improved fuel source was to come, of course, from petroleum. Petroleum production only began in 1851. The first well in the world was in Pennsylvania. This had followed failed attempts to dig for oil; the idea of drilling was borrowed from salt wells. Petroleum was developed to serve the markets for lighting oil (which increased with literacy rates) and lubricants (which expanded with mechanization, railroads, and steamships). Gasoline was of little use for either purpose and was often considered a waste product by early petroleum refiners. Costs of oil and gasoline fell as oil production expanded, especially with the opening of the vast Texas field after 1900.

A significant breakthrough occurred in 1885 when the German Gottlieb Daimler introduced the first high-speed internal combustion engine. This machine required gasoline fuel for rapid vaporization. Daimler's introduction of the carburetor, which both vaporized the fuel and mixed it in the right quantities with air for combustion, made this high-speed engine practical. Daimler's engine was much smaller and lighter than those that had gone before: He had specifically been looking toward markets in railroads, ships, and

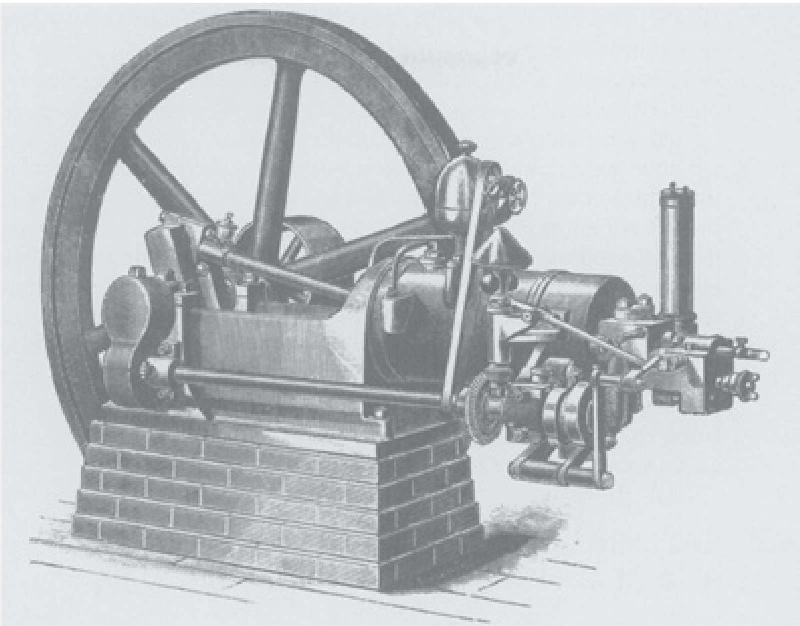

Figure 9.3 The Otto engine, 1870s: The pictured engine was capable of 4 horsepower. The fuel tank was placed outside the building in which the engine was installed.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

airships, as well as in industry. Shortly after Daimler produced his engine, Carl Benz of Germany developed the first internal-combustion motorcar.

It might seem at this point that the victory of internal combustion in transport was assured. Yet the success of the gasoline automobile depended on the solution of a number of tricky problems: Fuel and air had to be mixed so as to handle variations in speed and load; the engine had to be cooled; a transmission had to be developed so that the vehicle would not stall at low speeds; a reliable starting mechanism had to be devised; and gears and tires needed improvement. These fundamental problems were not all solved until the first decade of the twentieth century. Moreover, as with electricity, the automobile could only truly succeed as part of a system of complementary technological and organizational innovations. As we will see in later chapters, innovations in such areas as oil production and road construction aided this process.

Catching the Wave: The United States and Technological Leadership

The Second Industrial Revolution marks a turning point in industrial and technological leadership in the world. Britain had been by far the world's leading industrial nation since the first Industrial Revolution. Even well into the Second Revolution, British names still dominate the innovative process: Bessemer, Gilchrist Thomas, and Maxwell. Yet already the signs of the future role of Germany and the United States can be seen: German innovators included Siemens, Haber, Otto, Daimler, and Benz; Americans included Edison, Carnegie, and Henry Ford. Germany and France dominated development of internal combustion engines in the 1890s; only as American producers started serving their mass market did the technical lead cross the Atlantic a decade later. Germany also dominated late-nineteenth-century innovation in chemistry, but Americans followed soon after, aided by victory in World War I, which gave the United States access to German patents. The German and American electrical industries grew faster from the outset and would dominate innovation in the field for almost a century. In steel, the United States quickly adopted the Bessemer and Siemens-Martin processes to local needs and launched a series of improvements. The German industry stagnated until Gilchrist Thomas set it on the way to European supremacy.

Many have asked why Britain lost its lead in the late nineteenth century. The answer probably lies, at least in part, in the role played by science and education in the Second Industrial Revolution. Britain's early success occurred in an era of amateur tinkerers working far from the scientific frontier. During the nineteenth century, many European countries established school systems that placed a greater emphasis on science than the British did. Of particular interest were the technically oriented schools and universities developed in Germany and elsewhere. German universities became the center of world research in chemistry in particular.

Britain was not the first or last nation to lose the world lead in innovation. Italy and the Netherlands had once had their day in the sun when Britain was still importing most of its manufactured goods and technology. In the twentieth century, Japan wrested world leadership away from Germany and the United States in some fields. This is, perhaps, inevitable. The conditions that are conducive to one generation of technology need not be helpful to the next. Moreover, world leadership creates an obvious temptation toward complacency. It is often much easier for followers to catch up to and pass the leader with respect to new technology, for they do not have as much invested in support of the old technology.

The United States had developed an extensive education system over the course of the nineteenth century. As we have seen, cultural attitudes were conducive to a practical orientation, as opposed to the classical education favored in Britain. Even though the best students in chemistry and physics still went to Germany for graduate study, American universities were beginning in the 1880s to establish competitive programs in engineering and science. When Carnegie wanted to hire a chemist for his steelworks, the search was not difficult. Nor did Edison have trouble peopling his research facilities. Shortly after the turn of the century, American firms, first in electricity and chemicals, would follow the German example and establish industrial research labs.

The United States had other advantages. Its vast supplies of natural resources, especially iron and coal, gave it a significant edge. Yet we should not exaggerate the role of resources: The German chemical industry depended almost entirely on imported raw materials, and Japan also has been heavily dependent on resource imports. More important was the size of the American market. The United States had, after Australia, the highest average income in the world in 1900. It had a large and well-integrated domestic market, conducive to mass production. In the nineteenth century, it had already shown much technological precocity. The American System of Manufacturing was already heralded worldwide and would set the stage for the assembly line and continuous processing. The very progress that we have described in previous chapters, then, prepared the United States in important ways to lead the world technologically.

Urbanization in Late-Nineteenth-Century America

The transport developments discussed in earlier chapters had made it easier to transport food, building materials, and other goods to cities; as trade expanded, the merchants who organized trade naturally gathered in cities. The steam engine had provided a further impetus to city growth in the mid-nineteenth century by freeing industry from reliance on water power. It was, however, in the last decades of that century, and the first decades of the next, that city growth was most dramatic. Fourteen million Americans lived in urban centers in 1880; by 1920, that figure was 54 million, fully half of the American population. In some ways, this urbanization was independent of the technologies of the Second Industrial Revolution. Yet these technologies, and others, both encouraged and allowed the growth of cities.

The internal combustion engine, as we have seen, had many advantages over steam power. Electrification also had significant benefits for factories, though these would not be realized on an extensive scale until the 1920s (see Chapter 12). Nevertheless, these technologies provided further encouragement to large urban factories in the late nineteenth century. As well, production of chemicals, electrical products, and automobiles would come to concentrate in large urban factories.

Factories and offices had to be powered, and homes heated and lighted. Cities were thus dependent on the transport of large quantities of coal or oil via canal, railroad, or pipeline. The United States became one of the heaviest users of non-renewable energy on a per capita basis in the world during the age of coal and maintained that status in the age of petroleum. One could not have large cities, or large factories or office buildings, without transport of nonrenewable energy. The widespread use of coal or oil separated most Americans from the actual production of power, as had been the case when humans relied on their own muscles, animals, or chopping wood. Energy prices fell with technical advances in mining, oil wells, and transport, as well as the development of large urban companies that delivered energy to homes and businesses.

In Chapter 5, we discussed how railroads ushered in an era of large industrial corporations serving national markets. These firms, with their combined production, procurement, and marketing functions, needed large head offices to control their national enterprises. These head offices were usually located in large cities: the firms would then have access to service firms in advertising, finance, insurance, and other areas, and also be located at nodes in the national transport infrastructure. As the service sector grew in importance, these firms also clustered in cities to be close to their customers.

How could large numbers of workers concentrate in one place without facing overwhelming costs of commuting time or pollution? Railroads had stepped into the commuter market from midcentury, providing rail links to what soon came to be known as suburbs. As cities expanded, railroads often found that they faced too many road crossings in reaching downtown. A standard but expensive solution was to elevate the railroads above these roads; the development of new steels for bridge construction supported this process. An even more costly alternative was the subway; advances in tunneling technology (which flowed from the railroad sector) helped here, and new steels were again of great importance. Many engineers previously involved in railroad construction but displaced as the intercity railroad network was completed, found welcome work building elevated railroads and subways.

On mid-nineteenth-century roads,[3] horses pulled omnibuses to transport workers to factory or office. These were slow, and the one-hundred thousand horses or mules in urban service in the 1880s dumped tons of manure upon city streets. The number of horses in use had increased considerably in the nineteenth century: They also moved passengers and goods between railroads stations, between railroads and ferries across major rivers or ports, and between railroad terminals or ports and customers. The advent of steam-powered transport had thus increased the use of horses. Scholars generally presume that continued reliance on this technology (horses are indeed a technology for humans had domesticated them, bred them, and developed horseshoes, harnesses, and techniques for training them) would have severely constrained city sizes. Steam-powered trams provided one possible solution to the problem of horse transport but created their own pollution problem. They were also less efficient than horses in translating energy into work. In the 1880s, however, 180 cities turned to electric-powered streetcars. These provided an inexpensive and quicker means of getting workers to work, and any pollution was concentrated at the site of power generation rather than strewn throughout the city. Streetcars were a source of noise pollution, however, and in the early days, their greater speed resulted in numerous accidents with loss of life. Horses remained important in urban transport until the arrival of cars and trucks in the twentieth century.

A revolution in home construction technology aided the movement to the suburbs. By the mid-1880s, balloon frame construction, in which the house frame is made from cut lumber, had largely replaced timber construction. Sawmills produced lumber in standardized lengths and widths for use by builders. The cost of home construction thus fell, and many workers were able to afford a home for the first time.

American cities soon diverged from most European counterparts in one important respect: American cities embraced the skyscraper. The skyscraper itself depended on a host of technologies. Advances in the production of steel encouraged in turn the improved design of steel posts and beams. Whereas in buildings of stone, the walls themselves supported upper stories—and had to be made thicker for taller buildings—steel posts and beams could carry the weight of the structure (allowing large window openings, no matter the height of the building).[4] Early skyscrapers used cast iron columns and wrought iron beams: Cast iron was reasonably good for compression and wrought iron for tension. Steel, however, proved better for both purposes. The Carnegie steel works, drawing on experience in bridge construction, gradually convinced builders of this point. Chicago in the 1880s, rebuilding from the great fire of 1871, was the testing ground for steel skyscrapers; with each success, entrepreneurs and architects were encouraged to imagine even taller buildings. New York was another early site of skyscraper construction. Notably, steel skyscrapers could be built much more quickly, for work on the next floor could begin while lower levels were still under construction. Service industry firms—publishers, retailers, insurance firms—were the primary tenants of these skyscrapers. While the permissive zoning of North American cities played a role in the emergence of the skyscraper, it was arguably the role of American steel firms in developing and marketing steel construction technology that was the critical factor at work.

These firms discovered that Bessemer steel was unsuited to construction, but that open hearth steel was well suited, for it was more ductile and homogenous: The scientific investigation of the structural properties of steel was essential both in developing this technology and convincing engineers and financiers to employ it. Building codes in some cities were slow to reflect the advantages of steel—New York for many years required unnecessarily thick walls—and this slowed the development of skyscrapers (Figure 9.4).

An even humbler technology—the elevator—was also essential. Before the invention of the elevator, buildings were rarely more than six stories tall. While the elevator had been invented early in the nineteenth century, concerns with safety—as elevators occasionally plunged to the bottom of elevator shafts—limited their use for passenger carriage. In the 1850s, the Otis elevator company in New York introduced the safety elevator, with a braking mechanism that operated should the ropes lifting the elevator break. Once safe and reliable elevators were available, buildings soared. The word 'skyscraper' was coined to reflect the awe of observers toward buildings of fourteen floors. In the twentieth century, advances in elevator speed were critical in allowing increased heights, for the slower elevators of the 1880s would have absorbed too much internal space in order to transport office workers to the top. Elevators in the Woolworth Building of 1913 traveled 700 feet per minute, those in the Empire

Figure 9.4 Building a steel-framed skyscraper in New York, 1906.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

State Building of 1931, 1,200 feet per minute. In addition to steel trusses and safety elevators, a host of other technologies had to be developed for skyscrapers: For bracing these structures against the wind; anchoring the structure to the ground; fireproofing; heating, cooling, ventilating; plumbing for fresh water and sewage removal; and electrical wiring. We might make special note of fireproofing: Large urban fires had long been a problem in the United States due to a heavy reliance on wood in construction (even of buildings faced with stone or brick, and even early steel structures) and lax building codes compared to Europe. It was soon appreciated that skyscrapers would be deathtraps in case of fire; building codes came to insist on the use of fireproof building materials and especially the provision of fireproof stairwells. The development of concrete as a building material was of key importance here.

The incidence of fires was also reduced by a shift from wood or coal to gas and (much later) electric heating, and a shift from kerosene lamps to gas lamps early in the nineteenth century, and then to electric lighting from the 1880s. These transformations also served importantly to reduce air pollution and to concentrate this at the site of power production. Cities in the Midwest such as Chicago, St. Louis, and Cincinnati had suffered from coal-based smog in the mid-nineteenth century dense enough that work stopped on the worst days: People complained of coughing and breathing problems. Electricity had a further advantage in a time of rapid urban expansion: It was much easier to string wires from house to house than to connect these to gas mains.

Some outlet had to be found for the human and other wastes that large human populations inevitably produce. This had been a problem for cities since the dawn of urban civilization; it took on a new importance as population density expanded. Outhouses could not serve large urban concentrations; some outlet for sewage was essential. The toilet had been invented in 1810 in London; there were only 10,000 of these in New York in 1856 for a population of 630,000. By 1888 a third of New York's population had toilets. If not connected to sewers, toilet use tended to cause overflows from cesspools into urban ditches. As the germ theory of disease gained scientific credence by 1880, and public awareness after that, cities were further motivated to remove potential health hazards, such as human wastes, from their cities. They were also motivated to provide clean drinking water to citizens: This had been achieved in most American cities by the 1880s, as even the poor proved willing to pay for the service. Whereas cities had at first focused on providing water that looked and tasted good, in the 1880s water was tested for a variety of contaminants. The American rapid sand filter, which greatly limited the spread of cholera and typhoid, was introduced to waterworks in 1885. Some cities had to pump water dozens of miles by 1900, but Chicago relied on purified water from Lake Michigan: It then reversed the flow of the Chicago River to reduce pollution of its water source. Sewage systems followed decades after and proved somewhat more challenging to finance. A host of technological advances facilitated the provision of water and sewage services: The use of new building materials such as concrete and steel, better pumps, and improvements in excavation and welding tools among them. Of particular note, the humble water meter was invented in 1824 in Britain but perfected in the United States decades later: This allowed utilities to charge residents for the water they used while discouraging residents from wasteful use. As water and sewerage systems grew in number and complexity, hydraulic engineers were trained in best practices.

As cities grew, it became harder and harder to cart the garbage away. The use of disposable products and packaging exacerbated this problem: Already in the late nineteenth century, Americans produced much more waste than the average European. Trucks powered by internal combustion could remove garbage more quickly than horses. But what to do with it? Incinerators and recycling were in place by the end of the century; sanitary landfills were developed from 1920.

Environmental histories tend to stress the late-nineteenth-century agitation for National Parks, or the formation of the Sierra Club. The period was also characterized, however, by a great deal of urban environmentalism, most often spearheaded by women. Citizens worried about air and noise pollution, sanitation, and the provision of green spaces. Volunteer youth corps were mobilized to clean garbage from city streets. These environmental groups were optimistic that with the right policies and technologies American cities could be made healthy and livable. They noted that noise and air pollution were signs of industrial inefficiency: If moving parts were built correctly and lubricated, and combustion more complete, both would be reduced. Water and sewer systems were the priority of these groups, followed by garbage removal, air pollution and, finally, noise pollution. Note that scientists did not well understand the health risks of air pollution until the twentieth century.

Notes

1 There had thus been natural plastics such as clay, gutta-percha, and shellac. The word ‘plastic’ has come to be associated with synthetic products.

2 The Corning Glass Company drew upon scientific expertise to develop ‘Pyrex’ cookware in 1916. This product would be steadily improved through the interwar period, and the technology would provide a base for experimentation with what would become ‘Corelle’ dinnerware thereafter.

3 Cobblestones, bricks, and granite blocks all proved poorly suited to heavily traveled roads. Natural asphalt was first used in Paris in 1838. Asphalt was first used in the United States in New York in 1865 and was common by the end of the century.

4 Chemical knowledge was also applied to the production of glass, which presented its own scientific and technological challenges. Special glasses were designed for construction, as well as automobiles, lightbulbs, and a host of other modern uses. By the 1930s, glass could be made strong enough that architects like Frank Lloyd Wright considered it a building material in its own right: Entire walls were made of glass.

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10 Technology and the Modern Corporation

Technology played an important role in the increase in size of American business enterprises over the course of the nineteenth and twentieth centuries. The railroads, with their large capital requirements and necessarily far-flung administrative structure, were by far the largest American corporations in the nineteenth century. Later corporations borrowed the mechanisms that they developed for supervising geographically separate middle managers. The railroads also encouraged the growth of other businesses by increasing the access of many firms to much more extensive markets. Large national retailing companies were the first to appear. Sears and Montgomery Ward were established as mail order distributors through railroad delivery.

The further development of mass-production technology was also critical. It was both a cause and an effect of the growth of the modern corporation and the expanding market. For example, machines for cheaply placing fluids such as soup and ketchup in cans were developed in the 1880s and were put to use by new firms such as Heinz, Borden, Cadbury, Proctor & Gamble, and Colgate. These companies simultaneously exploited the new advertising medium of national magazines to promote name-brand loyalty for their products. As seen in Chapter 5, they relied on the railroad to reach that market. The growth of the corporation was dramatic from the 1880s. In 1885 there were only five companies besides the railroads worth more than $10 million. By 1897 there were eight worth more than $50 million; In 1907 there were forty, and by 1919, one hundred. The industries most affected were food, chemicals, oil, metals, and machinery. Although non-technological factors also played a role (especially a favorable legal climate), new industrial processes and product innovation contributed mightily to the emergence of modern corporate America. Especially noteworthy was the increasingly centralized development of technology.

The Role of Corporate Research

The growth of the modern corporation was closely linked to organized technological development. The new technology associated with the Second

Industrial Revolution was often beyond the capabilities of the isolated inventor. The industrial research laboratory first emerged in the United States in the electrical field, but soon expanded to chemicals, electronics, automobiles, pharmaceuticals, and oil. General Electric (GE) opened the first corporate research lab in 1901, followed by Du Pont and Parke-Davis in 1902, Bell in 1911, and Eastman-Kodak in 1913. However, the emergence of large corporations with managerial hierarchies (and the development of the engineering profession) meant that industrial research, albeit on a smaller scale, also emerged in industries such as telegraphy in which the scientific base was less complicated. There were more than 1600 labs by 1930. Even the Great Depression could only slow this expansion: There were more than 2,200 labs in 1938. The number of jobs in labs rose from 6,000 in 1920 to over 30,000 in 1930, over 40,000 in 1938, 300,000 in 1962, and 800,000 in the late 1980s.

These large laboratories provided powerful companies with a high (although volatile) rate of return on their investment. By continually improving their product lines and production technology, these firms could maintain and expand their share of the market. Thus, industrial research may be an important cause of industrial concentration. Of course, without the large firms who alone could afford large research labs, it is difficult to imagine how many costly and complicated projects that led to such innovations as nylon and the transistor would have been successful. University and government facilities would only have been able and willing to produce some of these products. Large companies made possible new technological research.

The dominance of research by large firms need not be positive. Successful companies that have monopolized their market may cease to innovate. Large corporations may stifle innovation with excessive bureaucracy. Historian David Noble has noted that the American patent system was designed to encourage and protect the individual innovator. From the 1870s, however, it was used increasingly to enhance the economic power of major corporations. Companies created labs to produce a constant stream of patentable minor improvements to a core technology. GE's lab was set up primarily to protect its market position in lightbulbs, Bell's its market in phones, and Eastman Kodak's its market in cameras. These companies often also hired patent lawyers to fend off independent competitors and, when necessary, to induce the independents to sell inventions to the large corporations. Thus, Noble claims, corporations created 'patent monopolies' that not only protected them from competition but also narrowed technological development to fit the interests of these firms rather than the society as a whole.

There is a natural progression in technological innovation: In the early days of a new product, there may be many variants and intense competition, but as the technology comes to be standardized, a small number of firms may dominate, and these will focus on production technology and minor improvements to the new technology. Historically, new technologies are often adopted by entrants to an industry, who thereby take over the role of the dominant firm from those with expertise in now-outdated technology. Industrial research labs reflected this dynamic: Though uniquely capable of some major innovations, they were often best at developing production technology and minor improvements to products.

Even so, independent innovators have not disappeared in the twentieth century. One study of the 70 most important innovations of the first half of the twentieth century found that over half came from independent inventors. Large firms are probably much better at producing the series of incremental innovations that absorb the greatest costs of research, than at creating such breakthroughs in the first place. Oligopolistic industries—in which several firms share a market—have devoted larger portions of their income to research than monopolies or sectors that are more competitive. They may provide the best balance between financial capability and competitive pressure. Nevertheless, despite the often-conservative role of corporate research labs, over time they have made major product innovations, such as GE's lab has done in X rays and vacuum tubes.

Edison and the Electric Industry

Thomas Alva Edison (1847–1931) was a legend in his own time, for he epitomized the characteristics that nineteenth-century Americans admired about themselves. Despite his lack of formal education or family wealth, his pluck and luck brought him fame and fortune. He was respected as a traditional individualist, whose hard work and practicality produced remarkable success. He lacked a systematic background in science and was incapable of adjusting personally to the corporate hierarchy. Yet Edison was also modern, in tune with the most advanced technology of his time, skilled in addressing the demands of the market, and able to organize a team of specialists to help him innovate. Edison helped fund the journal *Science* in its early days and sought (often in vain) the respect of scientists, but he emphasized that he cared about whether things worked, not why. In these ways, Edison was a transitional figure, with one foot in the era of the prescientific 'tinkerer' and another in the age of the corporate inventor.

Edison was close to the cutting edge of technology in his time. In his late teens, he began working as an itinerant telegraph operator and, like others, he devoted much thought to improving the telegraph. Edison reached maturity just as electricity was on the threshold of revolutionizing the way power was generated and utilized. His first patent, in 1868 (when he was 21), was for a system to electronically tabulate votes in the legislature. When members of Congress proved uninterested, Edison vowed never again to waste his time on a technical development without first ascertaining that there was a market for it. The following year he moved to New York, perhaps with the expectation that he would best be able to find both financial backing and potential markets there. His first profitable innovation was an improved stock ticker, for which he received the then-astonishing sum of $40,000. He was amazed at this offer and became even more committed to a career as an inventor. These funds provided the basis for his inventing enterprise.

Edison quickly recognized that modern inventing required integrating the skills of specialists. He hired at least three researchers who would achieve fame in their own right: John Kreusi, who would work with Edison at Menlo Park, and later be chief engineer at General Electric; Sigmund Bergmann, who would establish a substantial electrical manufacturing concern in Germany; and Johann Schukert, who founded another German manufacturing firm that became Siemens-Schukert.

Edison was not well suited to the corporate hierarchy himself and was uncomfortable in the day-to-day business of managing a modern organization. Instead, he devoted himself to a series of research labs, which he called invention factories, to develop a wide range of marketable products. After a couple of years of operating a small laboratory in Newark, New Jersey, Edison established the much larger Menlo Park laboratory in 1876. Still, his staff never numbered many more than fifty. Edison always referred to these people as "friends and coworkers." He drove them hard (or, as one worker described it, made the work so interesting they chose to work long hours), but also sang songs and smoked cigars with them during late-evening breaks. In so doing, he showed that it was possible to manage innovation. His lab was not the first in the United States but was for many decades the largest and most successful.

In the early 1870s, Edison patented some improvements to the telegraph that allowed two messages to be sent in each of two directions over the same wire at the same time, rather than only one in one direction as previously. After quadrupling the productivity of telegraph cables, Edison, at the suggestion of Western Union—which provided much financing of Edison's research—turned his attention to the telephone and developed a much more sensitive carbon-based transmitter and receiver (initially in an attempt to get around the Bell patent). He developed the first phonograph in 1877. Edison had had earlier thoughts about the telephone, but had doubted its commercial value; likewise, Bell had conceived of the phonograph but doubted that there was a market for it.

Rather than developing the phonograph's market potential, Edison shifted immediately to inventing electric lighting. This project illustrates Edison's talent as an organizer. Although he often spoke critically of pure scientists, he soon added a chemist and physicist to the staff, along with an array of machinists and various specialists in electricity and metals. At Menlo Park, precise measuring devices were mounted on vibrationless tables anchored to the earth. Edison was justifiably proud of the $40,000 worth of equipment in his lab, as well as his vast library of scientific and technical material. He noted that scientific insights such as Ohm's Law and Joule's Law guided his researchers. Still, he was much less open to the pursuit of basic scientific research than would be the case in later industrial research labs (Figure 10.1).

Figure 10.1 Edison at his laboratory, 1904: He always retained his interest in hands-on experimentation.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Edison and his laboratory staff began to focus their energy on the problem of electric lighting in 1878, despite the fact that Edison had little experience with either lighting or electric power generation. The popularity of urban gas lighting (both indoor and outdoor) convinced him of the commercial potential. Edison studied the potential market for illumination in lower Manhattan and estimated the price at which this could be profitable. This was a truly modern approach to invention, for Edison was concerned not merely with producing a practical electric illumination, but he also recognized that he had to develop a method of low-cost electricity generation and transmission.

The first trick was, naturally, the light itself. Early in the century, it had been shown that various materials gave off light—became incandescent—when an electric current passed through them. Most, however, quickly burned up. Edison experimented with many filament materials, including platinum. We do not know precisely how Edison chose materials for experiment. Chemistry doubtless played some role, even though Edison captured the public imagination with stories that he tested thousands of types of vegetation. In the end, carbon (which was used in other Edison creations, such as the telephone transmitter) proved to have the resistance necessary for a commercially feasible electric lamp. It would not only last many hours but would require little electric current. Edison was only successful, though, by creating a better vacuum within the lightbulb so that the carbon did not oxidize.

The filament, in turn, determined the nature of other components of the system. The generator, in particular, had to be capable of producing a small current of high voltage. Edison recognized that generators designed for arc lights were inappropriate to his purpose. His team soon created a generator that more than doubled the output of its predecessors. Between the generator and the light, Edison's lab had to develop new junction boxes, switches, and especially meters. Fuses were invented to prevent overload and reduce the risk of fire (which naturally made potential consumers of this new product anxious). In those days before plastic, insulating miles of wiring also presented difficulties; cardboard was used before low-cost natural rubber became available.

Menlo Park closed after five years and hundreds of patents. In 1881, Edison shifted his efforts to the operation of his electric lighting system in New York. In 1886, Edison returned to his first love and opened the even more extensive West Orange Laboratory. He foresaw its primary goal as the development of new electric apparatuses for both home and workplace and wanted to be able to combine innovation and manufacturing on the same site.

Because the new venture was much larger than the one in Menlo Park, Edison found himself increasingly playing the role of manager and executive. He could no longer play an active, guiding role in the many research projects his lab undertook. He struggled with the question of how much freedom to give his staff. At one time, more than seventy different research projects were underway. This was likely too many. West Orange was still responsible for numerous improvements to electrical systems, the creation of a mass-market phonograph, the storage battery, and the movie camera. These innovations kept Edison in the public eye through World War I.

Still, none of Edison's later inventions had the success of his earlier triumphs. In part, this was because Edison did not recognize the potential market for the phonograph and movie camera, as he had the lightbulb. Whereas the lightbulb replaced gas lighting, the phonograph and movie camera were novelties. Edison geared the phonograph toward a business market for dictation and thought that people would want to watch movies individually rather than on a large screen. He remained a folk hero until his death in 1931 and was a close friend of such modern industrialists as Henry Ford and Harvey Firestone. Ironically, the large integrated corporations that these men represented had ushered in a new era of industrial research with little place for a facility such as Edison's (Figure 10.2).

Edison General Electric and Thomas Houston merged to form General Electric in 1892. The new GE Company would take a very different approach to research than did Edison. Its research lab, set up in 1901, was much more focused than was Edison's, concentrating on developing and protecting its strong position in the lightbulb market. GE developed an improved carbon filament in 1905. Filaments based on the newly isolated tungsten further

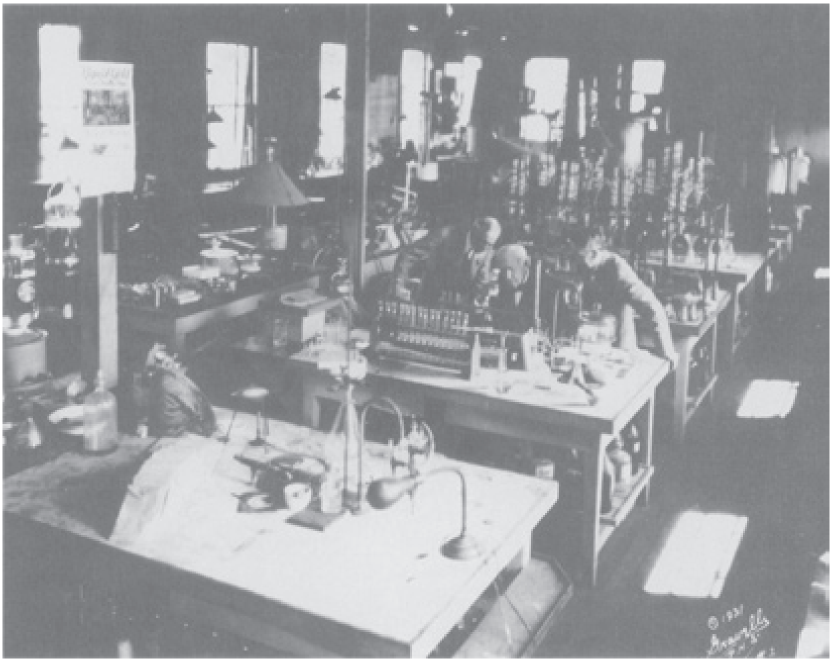

Figure 10.2 Harvey Firestone, Thomas Edison, and Henry Ford at Edison's laboratory in 1931. The three, famous for innovations in tires, electrical apparatuses, and autos, respectively, became close friends and often vacationed together.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

doubled energy efficiency in 1912; and when in 1913 GE wound tungsten filaments into tight coils and filled the bulbs with argon and nitrogen, efficiency improved another 50 percent. These improvements (along with cheaper electricity) reduced the cost of lighting by three-quarters between 1910 and 1930, and lightbulb use multiplied by sixteen.

General Electric's lab did slowly branch out from research focused on the lightbulb. It was responsible for significant advances in AC electricity transmission. It developed X rays—and for a year attempted to genetically modify plants (employing biologists alongside other scientists) with X rays, succeeding only in generating one desirable lily. It produced, as we shall see, many of the components essential to radio. Success with X rays and radio encouraged an even broader approach to research after World War I. This was accomplished, however, in an entirely different environment from Edison's labs. The research was pursued in line with the productive capabilities of the firm. Goals were quite clearly set from above. Edison's hostility to basic scientific research was replaced by a willingness to embrace such basic research if it would aid the commercial activities of the firm in the long run. Laboratory reports, which

Edison had shunned, were expected. Although Edison had paved the way for the modern industrial research lab, it would take a form that he would scarcely recognize. It did, though, continue Edison's practice of bringing together researchers with differing areas of expertise.

Tesla and Westinghouse

Edison was long an advocate of direct current. This served his purposes well in providing electric power to compact urban areas. It soon became apparent, though, that there was much less power loss when transmitting high-voltage alternating current over long distances. Both the utilization of hydroelectric power potential and the service of dispersed customers would depend on the use of alternating current. George Westinghouse, who had previously had both technical and commercial success developing air brakes and signal systems for railroads, saw the commercial potential of AC transmission and began developing regional transmission systems from 1887, improving upon European ideas in the field. In 1886, Westinghouse's William Stanley had perfected the first transformer capable of increasing voltage for low-cost transmission of alternating current and then lowering it for use. Still, it was not clear for some time which system was superior.

A key innovation would be a motor powered by alternating current. Many were seeking to devise such a motor at the time. Nikola Tesla, an immigrant who had learned his physics in Austria, made the breakthrough. His solution involved multiple AC currents and a rotating magnetic field. Tesla is less famous than Edison because he relied on Westinghouse and others for financing and licensed his innovations rather than developing them himself. He wanted to create a perfect AC system, which would have required four transmission wires rather than two; Westinghouse instead encouraged Tesla to develop techniques for allowing the Tesla motor to work with existing transmission systems. Tesla's very aloofness from the commercial world has attracted admiration from many, as has his advocacy of interstellar communication and prediction of costless energy production. His idealism and search for perfection may have played a role in the fact that he had limited success with any innovations after 1894. Alternating current, though, was victorious by the 1890s, and the first sizeable generating plant was built at Niagara in 1895.

Bell and the Telephone Industry

The second half of the nineteenth century was characterized by both rapid urbanization and the development of national distribution networks. New York City would have a million inhabitants by 1880. From 1847, the telegraph had begun to meet the need for improved local and long-distance communications. Many sought further improvements, especially in the 1870s with new developments in the understanding of electricity. Innovators at first focused on increasing the speed and capacity of the telegraph, but the telephone was the main achievement of that decade.

The earliest telephone was hardly a sophisticated piece of electronic technology. It required much less scientific and engineering knowledge than did the development of the electric light. It was, however, a less obvious outgrowth of electrical understanding than other advances. It is thus not surprising that its inventor, Alexander Graham Bell (1847–1922), was not an expert in electronics. Instead, like his father, Bell was a teacher of the deaf. His invention of the telephone came as an unexpected result of research related to the character of sound and speech. While teaching in Boston, Bell taught himself modern physics, from which he probably learned the basics of electromagnetism. It had been known for decades that if a wire were coiled around a core of magnetic material such as soft iron, and that core magnetized, a current would be induced in the wire. Bell's innovation was to recognize that if a diaphragm (analogous to the eardrum) were placed near the magnet and vibrated by sound waves, this would induce an electric current. This current, in turn, would produce an identical vibration in a similar diaphragm on the receiving end. This innovation required no scientific knowledge beyond that already embodied in the telegraph. It did reflect a willingness to break with the concept of intermittent transmission upon which the telegraph was based, and to recognize the possibility of the continuous transmission of current.

By February 1876, Bell had advanced his discovery far enough to apply for a US patent. Although Bell conceived the idea of the telephone in Brantford, Ontario, Canada, its final development occurred in Boston (Figure 10.3). Elisha Gray attempted to file a US telephone patent later on the same day as did Bell. Gray's activity is evidence of the fact that Bell was not alone in his research, though Gray's ideas do not appear to have been as well developed.

Sales of telephones were sluggish at first, as the sound quality of the early Bell telephone was poor. Others naturally sought to improve on the Bell design. Western Union, the telegraph company, acquired the Gray patent and hired Edison to develop a better system. In the meantime, Bell obtained Francis Blake's patent for an improved diaphragm. Bell won his patent battle with Western Union and others (eventually winning more than six-hundred infringement suits). The telegraph company abandoned the telephone business in 1879 after having built and installed more than fifty-thousand phones.

Only after Bell left the business in 1881 did the American Bell company's sales of telephones take off: Over the next 15 years, revenues increased by an average of 9 percent per year. Population growth and urbanization, coupled with the success of the first phones, made the Bell company a very profitable business, even after independent phone companies entered the race upon the expiry of the original Bell patent in 1894.

In the 1880s, The Bell company had no sophisticated research lab. Instead, it used the patents that came with its acquisition of Western Electric in 1879 from Western Union (ceded to Bell with a sizeable royalty as part of the patent

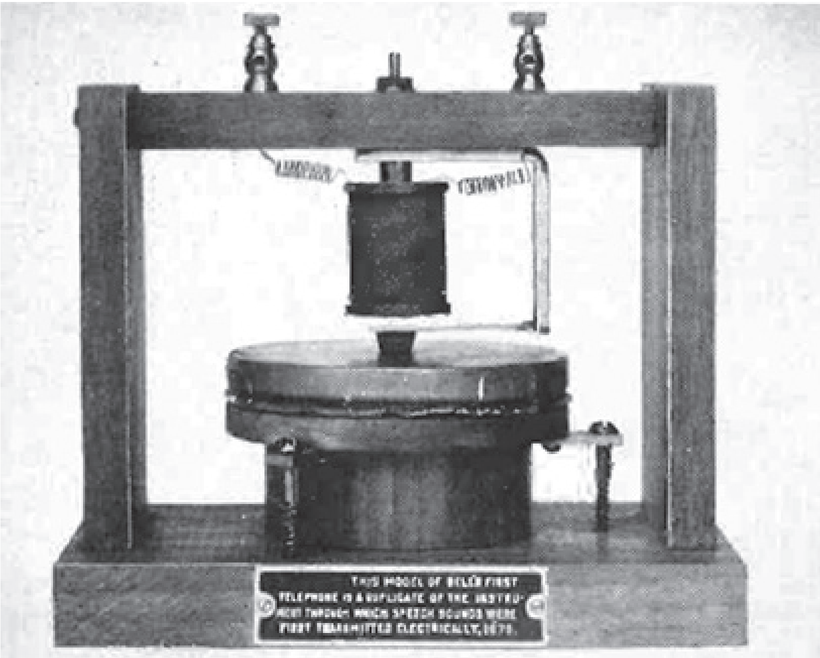

Figure 10.3 A replica of Bell's original telephone. This could transmit faint sounds.

settlement). Over the next decades, the Bell company would acquire many other patents. Even though the company began to do its own research, its engineering staff spent most of their time for the rest of the nineteenth century evaluating the inventions of others.

As with the lightbulb, automobile, electric streetcar, and other critical innovations of the Second Industrial Revolution, the widespread adoption of the telephone required a system of complementary technologies and institutions. In the early years, most phones were individually connected with another, so that contact could be maintained between offices, or between home and office. As early as 1878, Bell recognized that the future of his device depended on the development of central exchanges. These would not only give callers access to a range of other subscribers but would make it possible to keep track of the time of calls for billing purposes. Automated switchboards, though, would only be developed well into the next century (Figure 10.4).

The humble telephone wire itself was the scene of much activity. Proper design of protective cables was no easy matter. Moreover, the development of loaded wires was critical for making long-distance transmission possible. The pursuit of loaded coils caused the Bell organization finally to found what arguably became the most important industrial research laboratory in the United States—Bell Labs. The problem was that the pairs of copper wires that

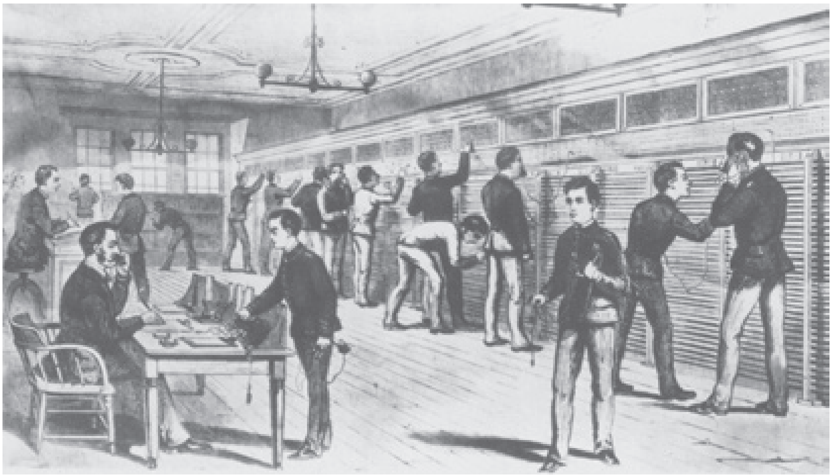

Figure 10.4 Washington, DC telephone exchange, 1880s. The telephone could only reach a truly mass market with automated switching. Note that telephone operator had initially been a male occupation.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

connected telephones to each other absorbed much of the electrical energy that carried messages. As a result, voices became incomprehensible beyond a distance of thirty miles. The solution was the loaded line, which involved the insertion of coils of wire around iron cores at regular intervals in each of the copper wires. This altered the electrical properties of the circuit, reducing electrical energy loss (attenuation) and facilitating transmission over distances of hundreds of miles. The English physicist Oliver Heaviside developed the science behind this device. Many years of research were necessary, however, before Heaviside's theory could be put to practical use.

In 1885, Bell hired Hammond V. Hayes, one of the first researchers with a Ph.D. in physics to work in the telephone industry. He was instrumental in separating the theoretical work from the mundane task of designing components. Hayes's superiors were willing to invest in loading-coil technology in 1898, as the expiration of the original Bell patent was forcing Bell into competing with independent phone companies. If Bell could dominate long-distance telephone lines with loaded coils, they reasoned, this communications giant could prevail over locally based independents.

When other Bell employees suggested that inductance, or the ratio of voltage induced to change in current, was the key to the attenuation problem, George Campbell, a trained physicist, set up an experimental apparatus to check for inductance. His experiment involved the insertion of coils in the wire, and he soon recognized that this design could alleviate the attenuation problem outside the laboratory. His familiarity with Maxwellian physics allowed him to design practical coils that provided the necessary inductance but had very low resistance. Campbell undertook scientific research to work out the full mathematical implications of Heaviside's theory so that he could predict the optimal distance between coils. Because of poor communications within the Bell company, others had filed conflicting patents before it did, and Bell was forced to pay hundreds of thousands of dollars to secure the patent rights to loaded wire; this brought home to management the value of in-house research. Then, when Bell began manufacturing loaded wire, it was necessary for the production arm to have regular access to researchers, as a series of minor difficulties arose.

The loaded wire had a brief but important history: As it still placed an upper limit of several hundred miles on transmission, research continued that resulted in electronic repeaters in the 1910s; these replaced loaded wire by 1925. Still, this experience had a lasting effect on Bell's attitude toward research. Further, by clinching Bell's dominance of long distance, it allowed the firm to start buying out the independents and establishing a national monopoly (even though Bell had to back down under threat of antitrust legal action in 1913).

The Bell companies were reorganized in 1907. One key element of the reorganization was the recognition of the need for ongoing profit-oriented research efforts that would be independent of, but in close contact with, both the manufacturing and legal departments. A research lab was officially designated in 1911, and this was recognized as Bell Labs in 1925. This research effort served to maintain Bell's ascendancy in the telephone industry for decades, with a stream of improvements to phones, switchboards, and cables. The problems of signal transmission and amplification especially would mean that Bell researchers would play a vital role in many of the electronic breakthroughs of this century: We will encounter them in later chapters in our discussion of the vacuum tube, the transistor, and the computer.

Du Pont and the Chemical Industry

The American chemical industry was more sluggish than the electrical sector in establishing international leadership in the field of research. American chemical firms took their lead from German chemical laboratories that had forged strong links with German universities, recognized worldwide as the leading institutions for the study of chemistry. German-trained chemists established both American graduate programs and corporate research labs. Leading the way was the Du Pont company.

At the turn of the twentieth century, Du Pont was an explosives producer. Because of the uncertain character of its market, and in fear of antitrust legal action because of its near monopoly of US explosives production, the company embarked on a program of product diversification. These efforts led Du Pont to own almost one-third of General Motors (GM) stock in 1929; but the company mostly concentrated on myriad fertilizers, textile dyes, pharmaceuticals, and other chemicals with varied and broad markets.

As part of this diversification strategy, Du Pont in 1903 became the first American chemical firm to establish an industrial research laboratory. Most of its early work consisted of purchasing European patents and developing new products from them in the United States. For example, in 1924, Du Pont obtained the American rights to the transparent film 'cellophane' from its French inventor. Du Pont put one researcher to work on this new product, and by 1927 he had succeeded in creating moisture-proof cellophane. Food processors and the new self-service grocery stores adapted cellophane for wrapping produce, meat, and other products. Sales tripled within three years, forcing Du Pont in the following years to spend millions on research to reduce production costs.

Chemical engineering had been a large part of Du Pont research efforts from the beginning. It had often proved difficult to scale up laboratory discoveries into successful commercial production. By the 1930s, Du Pont would develop apparatuses for automatically controlling various complex chemical reactions so that they could be performed continuously on a large scale.

Du Pont, like other American chemicals producers, was given a tremendous boost by World War I. Demand for munitions-related chemicals, as well as the cutoff of supply from German companies, allowed American producers to expand. American firms moved into dyestuffs and pharmaceuticals, which had previously been dominated by German firms. In the peace settlement after the War, the Allied governments claimed German chemical patents and made these available to domestic producers.

By the 1920s, Du Pont was beginning to develop its own ideas. It turned first to synthetically duplicating the kinked molecular chains that give natural rubber its elasticity. By 1931, partly by accident, it had succeeded in the laboratory. Because the chemical reaction was difficult to control, additional time was required before commercial production was possible. In 1937, with the development of odorless neoprene, synthetic rubber began to be used for gloves, shoes, heels, and other such products. Neoprene sales expanded sharply in the 1940s and 1950s and allowed Du Pont to more than recoup its heavy research investment.

While neoprene was Du Pont's first successful synthetic product, it was far from its most important. Du Pont also turned its attention to synthetic fiber manufacture in the 1920s. The company had been involved since before World War I in the production of rayon. The success of rayon (see Chapter 9) encouraged Du Pont in the 1920s to launch a research program for a truly synthetic fiber. By the end of the decade, it had been successful, but the fiber it produced was unable to withstand either washing or dry cleaning. Du Pont persuaded the research chemist Wallace Carothers to take the lead. Drawing upon his expertise in the area of polymers—the complex carbon molecules that are the basis of synthetics—Carothers' lab was able to create nylon in 1934. Notably, the success of Carrother's team depended on inputs from other research groups at Du Pont working in the fields of colloid chemistry and physical chemistry. Though Du Pont arguably exaggerated its contributions to science, it is nevertheless true that these research groups all developed an increased scientific understanding as they pursued commercial objectives. The chemical reactions for nylon production had to be so precisely controlled that it took another five years and $4.5 million before nylon could reach the public. Although Du Pont was aiming at the hosiery market, output during World War II was diverted to such products as parachutes, tire cords, and glider tow ropes. At war's end, a considerable market awaited not only nylon hosiery but tire cord and carpets. Nylon soon became the biggest source of profit in Du Pont history.

Du Pont was somewhat late in entering the field of plastics. Until well into the interwar period, German firms dominated research on plastics (due in part to German government interest in synthetic products for wartime use). Although useful for a range of products such as billiard balls and combs, plastic production remained minuscule. Growing markets in such areas as auto parts and radio components spurred Du Pont to look at the possibility of producing better and less expensive plastics. Again, it turned to foreign innovators. In 1936 it bought the patent rights to 'lucite' from its English producers.

Du Pont's research efforts yielded terrific results. In 1937, 40 percent of the company's earnings came from products developed since 1929. Its involvement across a wide range of products allowed it to bring together diverse areas of expertise. In the early 1920s, while trying to develop a new movie film, it accidentally discovered a new low-viscosity lacquer. Du Pont's ties with GM led to the consideration of a new car finish; 'Duco' was thus created in 1923. It allowed cars to be produced in colors other than black, reduced production time by weeks, and saved at least 15 percent of the labor involved in car painting. Duco would be the standard car finish well into the postwar period. With minor adjustments, Duco provided the basis for Dulux, which rendered the enameling of household appliances both easy and attractive.

Du Pont's experience appears to conflict with the claim that powerful companies were reluctant to develop new products. Its diversification strategy surely explains some of its openness to innovation. But Du Pont could have developed some of their products much earlier if they had been more focused. And some of Du Pont's discoveries—such as tetraethyl lead for solving the engine knock problem in automobiles, and the refrigerant Freon—were found decades later to have serious environmental side effects. Although these could not have been foreseen at the time, they indicate that new chemicals are not an unmixed blessing. In retrospect, many would disdain the slogan that Du Pont adopted in 1935: "Better things for better living … through chemistry." (Du Pont would drop "through chemistry" from the slogan in 1982 and move to a new slogan "the miracles of science" in 1999.) Yet, in many areas that is precisely what Du Pont provided.

Emergence of the Modern Engineer

America's large corporations had the financial resources to support industrial research, but they had to rely on the existence of a body of scientists, engineers, and technicians. Industrial research labs were from the beginning staffed by skilled professionals, most of whom were university trained. Even though the scientists often grabbed the headlines, industrial research labs required an even more substantial body of engineers.

Until the mid-nineteenth century, individuals often learned machine making, bridge building, and other engineering skills on the job. From the time of the early canal projects, a system of apprenticeship was in place to train engineers. Only after the Civil War, with the coming of the land-grant colleges, were engineering schools established, and new courses in the advanced subjects of electrical and chemical engineering introduced. Over time, engineering courses and programs came to emphasize scientific content and downplay practical experience; this shift was first noticeable in the new fields of chemical and, especially, electrical engineering.

Seeking increased social, economic, and professional stature, engineers formed trade organizations. These associations codified standards for the profession and attempted to more carefully distinguish those with the requisite qualifications from the amateurs or the assistants who performed specified tasks under the direction of an engineer. Local organizations soon generated national bodies. The American Society of Civil Engineers was the first of these in 1852; this reflected the dominance of civil engineering within the engineering profession before the Second Industrial Revolution. More specialized organizations followed: The American Institute of Mining and Metallurgical Engineers in 1871, the American Society of Mechanical Engineers in 1880, and the American Institute of Electrical Engineers in 1884. The twentieth century would see a blossoming of such organizations, including chemical, automotive, petroleum, nuclear, and environmental engineering groups.

As with any new form of organization, these groups gradually evolved into the sort of professional organizations with which we are familiar today. Their priority was to establish their legitimacy. This meant forging links with technical schools and colleges so that the training required for entrance into these professions could be standardized. It also involved a decades-long struggle for legal recognition of their status. The industrial research laboratories absorbed the ethos of professionalization from the outset and reserved their top posts for university-trained scientists and engineers. But it took some time for the engineering profession to attain formal educational standards. As late as 1870, only 5 percent of engineers had a college degree. With the steady pressure from professional organizations and a vast increase in college-level engineering programs, it became almost impossible to enter one of these professions without a university degree by very early in the twentieth century.

Most engineers, of course, were not directly involved in the production of new technical knowledge, but instead were trained to apply the existing body of knowledge to specific problems. Still, the increased expertise of the body of engineers aided technological progress in at least three ways. First, much of the production technology that emerged from the research labs required the skills of engineers to build and oversee the operation of this technology in the plant. Second, professional engineers were often teammates rather than subordinates to scientists in industrial research laboratories. (We have already seen that Du Pont recognized the value of chemical engineering very early.) Third, engineering professors themselves came to play a vital role in research. The extensive consulting links with industry that academics developed in the twentieth century have been critical in many areas, most recently in biotechnology and computers. Today there is clearly an advantage to industry of geographic proximity to university-based researchers.

What is engineering? Engineers naturally sought the prestige of science and defined their field as applied science (though those who worked most closely with scientists realized that scientists looked down on engineers). This had the unfortunate side-effect of perpetuating the misconception that scientific discovery always precedes technological innovation when the relationship between science and technology is in fact reciprocal. American government support of university research has been grounded in this misconception ever since Vannevar Bush produced his influential report *Science: The Endless Frontier* at the end of World War II; while support of science has been fruitful, a greater appreciation of the role of technology in scientific advance would have been helpful. Also unfortunate was the fact that both science and technology came to be associated with the white, male middle class that dominated both science and engineering; technology thus became identified in the popular mind with the 'male' factory rather than the 'female' home.

Since the 1870s, technological development has taken a decisive turn. The early, individualistic artisan-inventor, such as Cyrus McCormick or Robert Fulton, gave way to the scientifically trained corporate or university researcher. Men such as Bell and Edison, and the companies they founded, illustrate the transition from one era to the next. Innovation encouraged economic concentration. But the increasingly complex character of chemical and electronic invention also seemed to require extensive research labs to assure success. Free-thinking innovators may have survived in some corporate or university labs, but they almost all have degrees and access to expensive equipment.

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11 Technology and War, 1770–1918

Soldiers and inventors have always had a curious and complex relationship. The introduction of new weaponry has often given one side a decisive edge in battle and transformed the shape of armies and war. Given the stakes of victory and defeat, innovation in military technology has often been more dynamic than civilian innovation. For example, the military revolution of the late fifteenth and sixteenth centuries that produced effective cannon and muskets gave its European inventors a decisive edge over their Incan, Aztec, and Asian adversaries. Gunpowder weapons were quickly adopted by all the armies of Europe and forced painful adjustments in centuries-long methods of conducting war. Aristocratic castles that were vulnerable to cannonball were replaced by royal fortifications, defended by their low profile and thick earthen works. Bands of armored knights, soldiers armed with long pointed sticks called pikes, and archers were displaced by costly artillery and mercenary armies of musketeers, increasingly organized by strong central monarchies.

Yet, if technology has precipitated military revolutions, the linkage between innovation and warmaking has not always been strong. First, soldiers have often resisted innovation. Traditions of what constituted 'appropriate' warfare and social divisions between soldiers and inventors have often slowed the pace of innovation in weaponry. In fact, during the early phases of industrialization in the eighteenth and first decades of the nineteenth century, there was little weapons innovation. Only after 1820, and then with rapid acceleration from the 1840s, did military technological innovation make possible a new arms race. This rush to advanced weaponry coincided with a number of other trends. This included increased international rivalry, mass conscripted armies, business competition in arms sales, and an escalating interaction between innovation in offensive and defensive weapons. Especially important were the new methods of mass production that came with machine tools and the second industrial revolution discussed in previous chapters.

The result was dramatic: Military and industry increasingly were interdependent by the second half of the nineteenth century; arms races drove economies and threatened to turn cold wars into hot ones; and the old divide between the battlefield and the rest of society increasingly was obliterated in 'total war.' Perhaps most importantly, the gap between what soldiers expected in combat and what happened because of new weapons grew wider. Almost inevitably the scale of death and destruction increased dramatically. Although these changes would only be felt fully in World War II, they were well on their way in the American Civil War and World War I. In order to capture this revolution in the relationship between war and technology, this chapter must review many decades, focusing on the years from the Revolution through World War I. Although many of the changes will take place in Europe, they ultimately will affect the United States.

Legacy of European War: 1680–1815

To many Americans educated in the lore of the War of Independence, eighteenth-century European combat conjures up images of human tin soldiers, mechanically marching into gunfire with their red coats serving as targets. But this picture ignores a complex reality of war and military technology. Land warfare was built around the flintlock musket and artillery, weapons that reached their maturity by about 1680. The standard was the English 'Brown Bess' musket, which was introduced in 1682 and used until 1842. When the trigger was squeezed, flint scraped across the L-shaped steel frizzen over the priming pan producing a spark that ignited a gunpowder charge through a touch hole. This explosion, in turn, propelled an iron ball through a smooth barrel with enough force and velocity to pierce flesh.

The drawbacks of this weapon were many. It misfired often; to prevent this, the flint had to be sharp and the touch hole, clean. The flint lock musket seldom fired if the powder was not dry. It took from twenty to forty seconds to load, requiring a man in a standing position to insert the powder and the ball into the muzzle (the end of the barrel). Often soldiers bit into a prepackaged paper 'cartridge' containing the gun powder and the iron ball; then they poured powder down the barrel and into the priming pan before ramming the ball down the barrel. When fired, however, the ball, which had to be smaller than the diameter of the barrel, careened off the smooth inner surface of the barrel in an uncertain direction after exiting the musket. As a result, this weapon was scarcely accurate at hitting a four-foot square target at 40 yards. The complexity of loading the musket meant that it could be fired only about three times a minute.

These technological constraints dictated the tactics of combat, and this explains the strange behavior of the British 'red coats': Soldiers were drilled to march in close ranks of two or three deep. Given the weapon's range, the front row would hold their fire until they saw the 'whites of the eyes' of the enemy and then shoot simultaneous volleys, hoping to make up in numbers of shots for the inaccuracy and unpredictability of the individual soldier's weapon. The second row would then fire, 'protecting' the survivors of the first volley while that group reloaded. Casualties from combat and especially disease made soldiering an unattractive profession, drawing few beyond the desperate or 'impressed' (conscripted). Only iron discipline, based on endlessly repeated drills, made this form of fighting possible. The high cost of battle in terms of trained soldiers and expensive weapons made officers cautious in committing men to battle. Armies were tied to slow-moving supply trains and constrained by the weather (avoiding combat in the rainy seasons especially when powder got wet). Generals maneuvered for position and engaged in combat only at the last, and hopefully most favorable, moment.

In the Revolutionary War, some American patriots became snipers, using Pennsylvania rifles to pick off 'red coats' from behind trees. The rifle was distinguished from the smooth bore musket by spiraled grooves that lined the inside wall of the barrel; this 'rifling' gave the exiting ball a twist that made its trajectory truer and longer. Rifling had a history nearly as long as the musket. Nevertheless, the rifles were hard to load because the ball had to be larger (to 'take the rifling') and thus were very hard to jam down the muzzle (usually requiring a mallet and iron rod). Americans covered the ball in a greasy patch of cloth to ease the loading process, but the rifle still took much longer to load than a musket and the patch tended to foul the barrel. Thus, under conditions of battle, the more rapid loading musket was generally preferable. The rifle played a small role in larger battles; Napoleon even banned them in the French Army in 1805.

Artillery, like infantry weapons, also changed little from the seventeenth century. Cannon were basically iron or bronze tubes cast in a mold. Ballistics were primitive: Often the cannon was raised to a 45° angle, the ball and powder poured down the muzzle, and the powder lit with little effort at aiming or range finding. As we have seen, the Englishman John Wilkinson developed methods of drilling a more even hole in cannon, but because cannon were so expensive to produce, artillery pieces built in the 1540s were still being used in the eighteenth century.

Naval weaponry likewise was stagnant. Oak frigates fought in lines exchanging iron cannon balls at short range. This was because almost all the guns were fixed on the sides of warships, and were often inaccurate or unreliable in combat, thus requiring ships to form a line of battle. The objective was to cross the 'T'—that is, to pass a horizontal line of ships (where the full firepower of the side guns could be used) across a vertical line of enemy ships, where only bow guns could be used. This required a discipline and formal command as strict as in infantry combat.

Of course, there were some changes in the eighteenth century. The Prussians under Frederick the Great made their artillery more mobile and introduced grapeshot that tore into enemy infantry. The Frenchman Jean de Gribeauval in the 1780s introduced interchangeable parts to the artillery, and standardized cannon-balls. The biggest reform, however, was not in technology but in the organization and tactics of armies. The French Revolutionary army in 1793 introduced the mass-conscripted army, where soldiers were motivated less by harsh discipline imposed from above, than by patriotism and hope

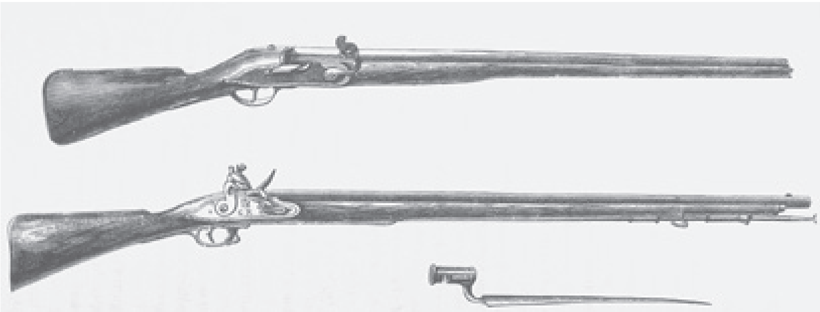

Figure 11.1 Classic early guns: On top is a matchlock. Notice the piece of rope (the match) that drops into the flash pan when fired, igniting primer gunpowder and propelling the projectile. On the bottom is the famous Brown Bess musket where the firing mechanism is flint.

Credit: *William Greener,* The Gun and Its Development, *1907.*

for advancement. The revolutionaries mobilized industry for war by setting up hundreds of small factories to make muskets and supplies. As refined by Napoleon, the French army abandoned the slow-moving supply train and thus gained the ability to strike quickly in mass. His armies did not use new weapons but appealed to the emotions of highly motivated soldiers to defeat smaller, less energized armies of peasants who cowered under traditional aristocratic officers. Napoleon also increased the number of artillery pieces, directing these with murderous effect on opposing troops to a degree never before attempted. All this made Napoleon invincible in endless wars between 1800 and 1812, even if his army finally succumbed to the vast plains and winter of Russia. Significantly, Napoleon made few technological innovations. He loved the ideal of hand-to-hand combat and encouraged the use of the bayonet. After Napoleon's ultimate fall in 1815, Europe retreated back to traditional armies. However, his doctrine of massive assaults greatly influenced later military leaders—even after technology increased the range and power of weaponry making these assaults much more deadly.

Naval technology and tactics changed even less during this period. Britain's Admiral Nelson went into the Battle of Trafalgar in 1805 against France on a forty-year-old ship, equipped with ancient smooth-bore muzzle-loaded cannon, with accuracy at scarcely more than 300 yards. Experiments in rocketry during the War of 1812 were abandoned thereafter. Naval professionals remained loyal to the doctrine of close combat of equal battleships, 'yardarm to yardarm.'

Why, we might ask, was there so little military innovation in the two centuries before 1850? Obviously, the high cost and time investment of manufacturing weaponry in the artisan age was an impediment. As we saw in Chapter 6, this began to change with the mass production methods of the American

System of Manufacturing in armories. Still, innovation in production did not necessarily lead to improved weapons. One factor in the stagnation of military technology was the commitment of officers to constraint in warfare and tradition. The French king Louis XV opposed exploding shells, for example, because of their apparent inhumanity. European officers were mostly visceral conservatives, aristocrats committed to feudal-era traditions of individual combat and the notion of war as a game. They believed that courage in combat and cunning in deployment for battle determined the course of battle, not innovation in weaponry. Combat was often deadly (although disease was often more harmful); and ordinary soldiers were treated like trained animals or tin men. However, leaders did not fight to the 'last man' for an idea or for total domination. 'Total' war, where the object was to destroy a competing ideology or a people's will to resist up to the material, social, and technological limits of the victor, was new in the modern world. We see a foreshadowing of it during the French Revolutionary and Napoleonic wars (1792–1815), when mass (sometimes conscripted) armies took the field; and the American Civil War fielded citizen armies devoted to a cause and equipped them with increasingly deadly weapons. Still, it was only in the twentieth century, when war was driven by ideology and extreme nationalism, that total war armed with advanced technology reached its peak.

A Weapons Revolution on Land and Sea, 1814–1860

Innovation did come. The transformation of the musket of 1815 into the modern repeating rifle of the 1860s revolutionized war. Interestingly, behind these changes was no strong desire for military domination; indeed, this period was as peaceful as any in the history of western civilization. Rather, innovation was incremental, advanced by new methods of manufacturing, and often motivated by notions of 'progress' or hopes of exploiting markets for replacing old guns. New weapons tended to be used first against animals or native peoples—who, to many European and American invaders, were barely different. And key innovations came from entrepreneurs like Eliphalet Remington and Samuel Colt, who seldom possessed any understanding about the wider implications of their innovations for combat. Military leaders shared this ignorance and often continued to prepare for battle as if they were still using the flintlock musket. As the years dimmed the memory of the mammoth battles of the Napoleonic era, people forgot what mass warfare could be like, or what impact the new weapons might have upon tactics designed for an earlier age of arms.

The first major change came about 1820, when the percussion cap replaced the often unreliable flint for igniting the musket's powder. The cap was a small quantity of mercury fulminate sheathed in soft copper. When placed over a 'nipple' or tube that led to the base of the barrel, and struck by the gun's hammer, the cap exploded, thus igniting the main powder charge in the barrel. Because old flintlocks were easily converted, hunters embraced the percussion cap and the British military followed by 1842.

A second change to the gun came in the 1840s, when the cylinder-cone shaped bullet (invented by Claude-Etienne Minié in 1846) gradually eliminated the traditional metal ball. A hollow base allowed the new bullet to expand when fired and to form a tight fit as it left the barrel. The bullet made rifling more practical because the bullet could now be made smaller than the bore, and this eased loading from the muzzle end. The expanding bullet easily took the rifling grooves and radically increased the soldiers' range—up to 1,000 yards by 1851 (though effective at 300 to 600 yards). The new bullet swept the old smooth bore muskets from the field in the 1850s.

Still, bullet and powder had to be separately dropped down the muzzle of the barrel from a standing position (and thus took almost as much time to load as the old musket). In 1811, John Hall offered a third way of improving on the gun when he patented a breechloader. This weapon was equipped with a hinged breechblock, allowing bullet and powder to be loaded from the lock (the firing mechanism) behind the barrel. However, the seam that separated the breechblock from the barrel was poorly sealed; thus, flame often flashed back on the user. This hazard, plus the loss of propulsion from the backflash, made Hall's weapon unpopular with soldiers. Only in 1859 did Christian Sharps, at Harpers Ferry produce a satisfactory single-shot breechloader that was used in the Civil War.

A fourth direction of innovation was the repeater and self-contained metal cartridge. Although Samuel Colt of Connecticut is famous for his 1836 revolver, this weapon was unsatisfactory because each chamber had to be individually filled with powder and ball. Central to the success of the repeater was the development of the integrated metal cartridge consisting of bullet, gunpowder, and percussion cap encased in a metal shell. A fully functional metal cartridge appeared in France in the mid-1840s with alternative firing mechanisms (rim and center pin with the latter dominant after the Civil War). By 1857, Horace Smith and Daniel Wesson had developed a metal cartridge revolver. In 1860, Benjamin Tyler Henry patented a lever-acting breech-loading repeating rifle supplied by 16 bullets delivered to the gun lock from a tube in the gun's stock (handle). This weapon was widely used in the West against native warriors and buffalo. The Spencer repeater with a magazine containing eight shots was used in the Civil War to a limited degree (Figure 11.2).

This new form of cartridge eliminated the time-consuming use of the paper cartridge and nipple-fitted percussion cap. When struck by the firing pin, the cap and then the powder exploded, causing both the metal shell and the bullet to expand. This made the bullet catch the grooved spiral rifling on the inside of the barrel as it was propelled forward, creating the characteristic spin that gave rifles superior range and accuracy over the smooth bore muskets. Despite these advantages, paper packages (cartridges) of powder and conical shot, along with separate percussion caps continued to be used throughout the Civil War. Artillery followed a similar path: By 1846, rifled breechloading cannon were developed in Europe with ranges up to 9,500 yards and were used by the French in 1859 in a brief war with Austria. Robert Parrott designed a rifled cannon used in the field and on ships in the American Civil War.

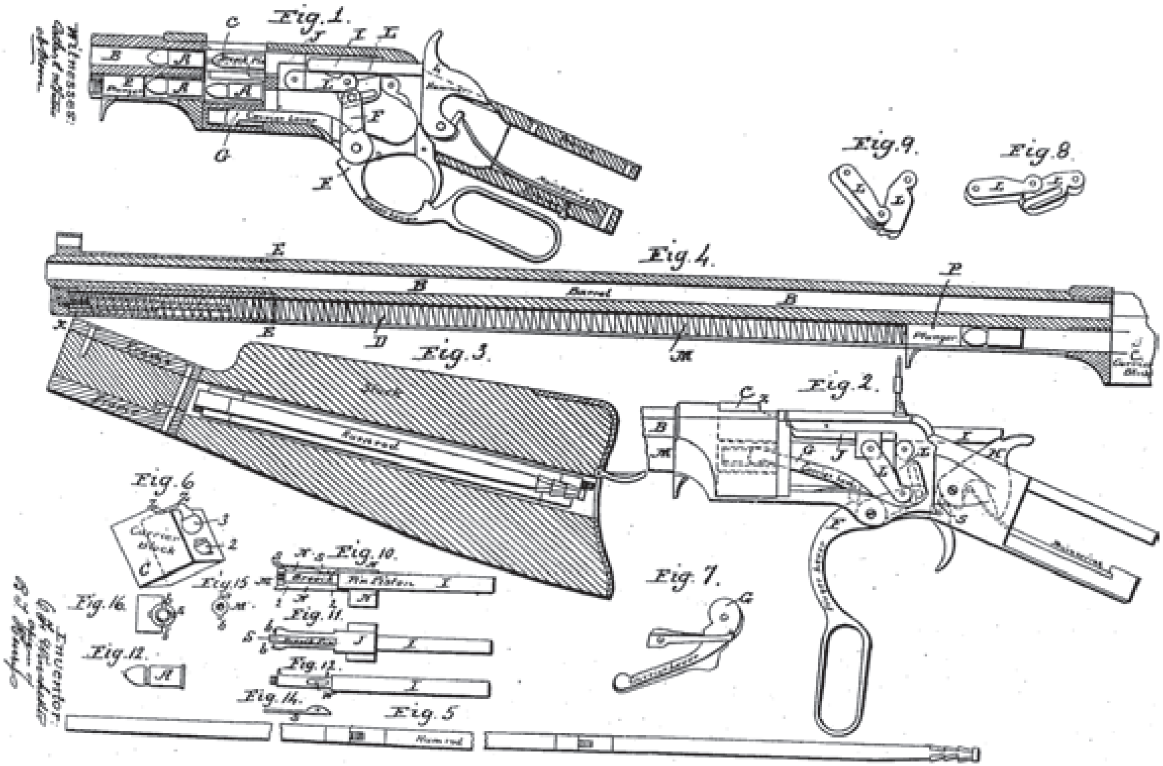

Figure 11.2 The patent illustration of the Henry repeating rifle with tubular magazine of sixteen rounds loaded in the stock. While a few were used in the Civil War, variations played a major role in Indian wars and the West.

Credit: *Courtesy of the US Patent and Trademark Office.*

A revolution in naval technology paralleled that of armies. A combination of iron and steel construction with steam power replaced the oak sailing ship. In a long evolution beginning in the 1820s, cheaper iron and then steel made possible the substitution of metal for wood. This had a number of wide-ranging consequences. Because iron and steel girders were up to ten times as strong as oak beams, the constraints on the sizes of boats (and number of guns per boat) were lifted. Iron and steel also made possible the compartmentalizing of the hull, thus limiting the intake of water if one section was pierced. Metal construction of course allowed the armoring of ships. This, in turn, encouraged offensive innovation in larger, more powerful shells. In 1823, Henri-Joseph Paixhans proved that exploding shells could devastate oak ships. But only after Russian explosive shells destroyed the Turkish fleet in 1853 did the French and English begin to iron-plate their old wooden frigates.

Tradition-bound navies everywhere were suspicious when Robert Fulton attempted in 1814 to turn his commercial steamboat into a warship. Naval authorities had some reason to doubt: The paddle and the engine of the steamboat were extremely vulnerable to enemy fire. Steam engines at that time lacked the power of wind-filled sails (indeed, it was not until 1873 that the first steamer was built without any sails used to supplement or back up an unreliable steam engine). Ocean storms destroyed paddles; inefficient engines demanded huge supplies of coal; and salt water quickly fouled boilers. As late as 1840, only 12 percent of the English fleet were 'tea kettles,' as officers contemptuously called steamboats.

The American Robert Stockton greatly improved steamboats when he added a screw propeller in 1843: It not only was more efficient than the paddle but less vulnerable to attack. More powerful compound steam engines developed in the 1850s were also critical, increasing power and saving coal and fresh water (a significant problem on long transoceanic voyages). By 1857, the British navy, having seen the superior maneuverability of its small steam fleet in the Crimean War, abandoned the old sail-powered warships altogether. The switch from sail to steam had many effects: It allowed more direct and faster oceanic naval movement, and it facilitated upstream river navigation, making it possible for Westerners to penetrate the continents of Africa and Asia. The English victory over China in the Opium War of 1839 to 1842, and the European conquests of colonies after the 1860s, all depended upon the steam-powered gunboat. At the same time, steamboat navies became dependent on coal supply stations that had to be scattered globally. This encouraged western powers to seize seaports and colonize countries far from home.

It was one thing to invent a more deadly weapon. It was another to reequip armies and navies, and to deploy mass armies. This required the full integration of industry with the military. The advantage of American interchangeable parts was vital in supplying mass armies and navies. Europeans began importing American machine tools for this purpose in 1859. In that year, the railroad was first used by the French for the rapid deployment of troops and supplies in a war with Austria in Italy. Railroads became the essential complement to an era of mass citizen armies that were emerging at this time, allowing war-makers to 'call up' and send to the 'front' millions of draftees, reservists, and volunteers (Figure 11.3).

Technology and Tactics in the Civil War

The impact of these weapons innovations became obvious during the American Civil War (1861–1865). On the eve of that conflict, Western military forces had embraced the percussion cap, bullet, and rifling. Breechloaders and repeaters were still rare, as were cartridges and firing-pin guns. During the Civil War, rifled and breechloading cannon were introduced in small numbers. And most *new* ships were steam-powered and armored. The Civil War was the first major war that combined this weapons' technology with mass production methods, the modern railroad, and the telegraph. These innovations had unexpected results on the battlefield, and in the war's course and outcome.

To begin, we need to explain why both sides in the Civil War never fully utilized the latest technology. In 1860, the US had a regular army of scarcely 26,000 (as compared to the Russian army of 862,000). Quickly, however, the armies of the North and South mobilized. There were 2.1 million soldiers who ultimately served for the Union and 1.064 million for the Confederacy. Given this lack of preparedness for this scale of fighting for several years, there were

Figure 11.3 A Civil War-era mortar transported by rail at Petersburg, Virginia (1864).

Credit: *National Archives and Records Administration.*

shortages of the new weapons. This meant that many soldiers were still issued smooth-bore weapons and some even flint lock models.

During the four years of the war about one million Springfield rifles were produced. These were single-shot muzzleloaders that used the nipple percussion cap and had an effective range of four-hundred yards. Lincoln's Chief of Ordnance, James Ripley, resisted the manufacture of Sharps breechloaders and Spencer and Henry repeaters until he was replaced in 1863. Ripley reasoned that the repeater was too complex for the untrained, volunteer Union soldier, and its capacity of eight and sixteen rounds per minute would mean that ammunition would be wasted. The special cartridges required for the repeaters (as well as their technical limits) added to the difficulty of using them in battle. But, at Lincoln's insistence, Sharps breechloaders and repeaters were manufactured in the last two years of the war. Despite the North's advantage in factory machinery and railroads, the Union lost many of its best rifles to the Confederacy. The machinery from the Harpers Ferry arsenal was captured and sent south. Still, the South's lack of manufacturing facilities meant that most of its modern rifles were imported from Europe and had to be supplemented by flintlock smooth-bores.

Even with this failure to fully use the new military technology, both sides made ample use of the rifle, and it had a devastating impact on battle. The key was the range of the new rifles. However, leading generals on both sides were strongly influenced by their youthful experience in the Mexican War of 1848, when smooth-bore muskets predominated and were used with great effect in close-order offenses and bayonet charges.

These 'Napoleonic' tactics, however, had a very different impact in the new rifle age. Given the longer range of the new weapons, attacking and seizing land became extremely difficult. The advantage clearly was with the defense (up to three attackers were required to dislodge one defender). Yet the South took the offensive in two-thirds of the first dozen battles, suffering losses of 98,000 men in the process. Likewise, Lincoln and other politicians favored 'fighters' like US Grant over cautious generals like George McClellan. Grant's Wilderness campaign of 1864 added 64,000 to the casualty list in seven days of attack, without dislodging the Confederates who were relatively safe in their trenches. The Battle of Gettysburg in July 1863 engaged 157,000 soldiers on both sides, with 17,848 killed and missing and 33,234 wounded. The grandsons of Civil War veterans would recognize the battlefield of 1863 in World War I: In both wars, officers ordered charges to overcome defenders quickly, but attackers were often decimated by rifle fire and artillery. In the Civil War, southern generals usually favored the 'valiant attack,' and suffered disproportionate losses.

Assault tactics that had worked well in the era of short-range muskets, had deadly results after the coming of the rifle and longer range artillery. The rifle undermined other 'glorious' military traditions: The cavalry charge could no longer intimidate infantry. The rifle's bullet easily reached horses and saber-wielding cavalrymen long before they got near infantry lines. Cavalry increasingly were used for reconnaissance, and rapid movement of soldiers to critical road junctions, for example. Despite the continued use of muzzle-loading artillery in the Civil War, these weapons still had a devastating impact on fortifications and infantry. Short-barreled howitzers were especially mobile and some rifled artillery increased the range of fire (up to 1,900 yards for the Parrott rifle). Gradually, mass attacks diminished as officers dispersed attacking troops and paid greater attention to cover. Soldiers recognized the value of axe and shovel to build log and earth works. Meanwhile, trenches were extended for miles to fend off attacks. Still, spectacular casualties were the inevitable result. And glory in decisive victory in battle was replaced by a war of attrition.

Southern access to European suppliers was essential for survival. This obviously required that the Confederacy prevent a Union naval blockade. Key to this effort was the conversion of a captured wooden steam frigate, the Merrimack, into the ironclad Virginia. When this 'secret' weapon steamed from Norfolk, Virginia, on 8 March 1862, it defeated a northern force of blockading wooden vessels. Southerners appeared to have found a way of keeping trade links open. But the next day the Virginia met the northerners' answer, the Monitor. This odd-looking craft with its low deck and single turret was barely seaworthy, yet its iron construction was a match for the Confederate ship in battle. Both fired at each other at close range, with little damage done to either boat. The secret weapon only produced a response in kind and led to a technological stalemate. Yet the effect was to defeat southern dreams of breaking the northern blockade (Figure 11.4).

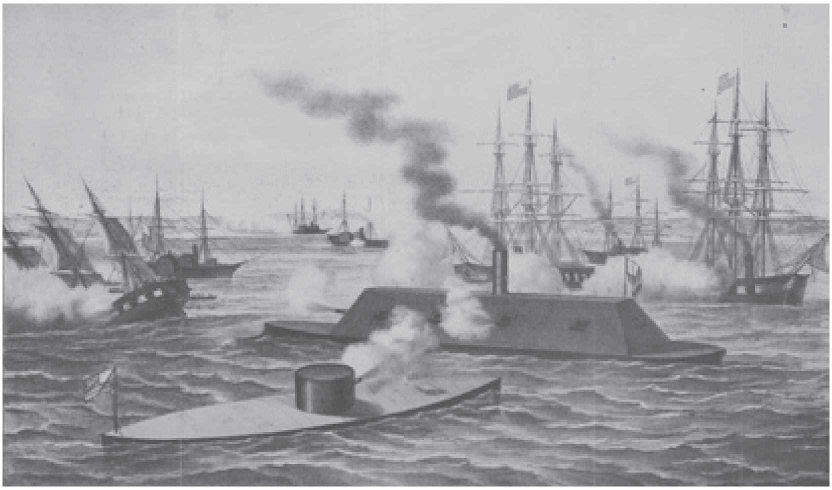

Figure 11.4 The South's Merrimac (Virginia) meets the Union's Monitor in a stalemate, 1862.

Credit: *Courtesy of Library of Congress Prints and Photographs Division.*

Expectations of quick victory on the battlefield, won by brilliant generalship and courageous soldiers, were dashed; so was the dream of a decisive new weapon. Instead, the Civil War became a war of attrition. Ultimately the winner was the side with the greatest industrial might. Obviously, the South with its far smaller non-slave population (roughly 5.8 million as opposed to 21 million for the North) had a much smaller pool of men to draw upon for the army (an increasing problem as the war progressed). Roughly twice as many men ultimately fought for the Union as for the Confederacy. Still, many assumed that the southern advantage in rural males accustomed to the use of guns would give them an edge. The long border between North and South was supposed to make invasion and occupation of the South very difficult.

But Confederate strategists underestimated the industrial and technological advantage of the North. The Union had about 100,000 industrial units compared to the South's mere 18,000. Moreover, the Northern advantage grew during the war, as railroad and industrial capacity expanded despite manpower diversion to the war. It was during this war that the United States began to tap the talent of scientists for national defense: The National Academy of Science was created to undertake defense research, the beginning of a long cooperation between the military and science. Perhaps the greatest advantage of the North was its superior railroad system—21,000 miles of track compared to merely 8,800 miles in the South at the beginning of the war; and this contrast only grew as the war wore on. Sherman's well-known march to Atlanta required immense trains to supply his 100,000 men and 35,000 animals. By contrast, the South's meager rail system was so worn-out and decimated that, by the Spring of 1865, food from Alabama could not be delivered to the 155,000 remaining Confederate troops in Virginia.

The Civil War cost about 620,000 lives, more than the American soldiers lost in both World Wars and Korea put together when the nation's population was far greater. While enmity between the two sides was important in explaining the carnage, technological changes in weaponry, combined with outmoded military doctrine were critical factors in the unprecedented death toll.

Few Europeans learned the lesson of the American Civil War about the misfit between traditional battle doctrine and the new weapons technology. To most European military observers, the American disaster was merely the consequence of poor training and inept leadership of the 'backward' American military. Compared to the well-prepared armies of Prussia, the armies of the Civil War appeared to Europeans to be amateurish. The impression that the Civil War was merely an anomaly was reinforced when the United States rapidly dismantled its armed forces in 1865, and its army and navy were very slow to innovate thereafter. Thus, Europeans took their clues about future wars and technology from Germany, whose armies won two quick wars in 1866 and 1870, over Austria and France. Observers concluded that the German advantage in technology (especially its skillful use of railroads and the breechloading steel cannon) meant quick victory.

This new faith in technology helped to stimulate an arms race, as European rivals mobilized their industrial and scientific resources to gain the 'edge' in potential war. Yet all contenders forgot that technological advantages were almost always temporary and usually only prompted imitation or a counter-weapon. At the same time, military leaders continued to believe that victory came from the 'moral power' of cunning general staffs, courageous soldiers, and even racial superiority. Europeans (and later many Americans) held a contradictory faith that technological advantage meant quick victory and yet that war remained primarily a contest of daring soldiers. These convictions led to the modern arms race, and disaster in World War I.

The New Arms Race after 1870

A key to understanding the gap between military thinking and technology is the fact that weapons changed dramatically after the 1860s, without being used in the war between the major powers. For example, the American Gatling gun of 1862 (a four- to ten-barreled machine gun) had little impact on the American Civil War. Only later did the for-profit companies of Maxim (1885) and Browning (1895) produce lightweight, single-barrel machine guns. These weapons came too late for war between the major powers in the nineteenth century; rather, they were used against Africans. For example, a small British force equipped with the latest repeaters and machine guns literally mowed down eleven-thousand Dervishes in the Sudan in five hours; the British lost a mere forty men. Although many of these Africans possessed old muskets (purchased in a flourishing used-weapons market), the arms gap made their cause hopeless. This experience prepared few Westerners to understand that the machine gun favored the defense.

Smokeless gunpowder (1884) eliminated the smoke that formerly identified the positions of gunners and hid the field of attack. It also was a slower, more evenly burning powder. This property allowed for longer, thinner barrels on cannon: Slower combustion made possible a greater thrust and the longer barrel also meant a longer range of fire. Weapons inevitably became more deadly.

Army officers did, of course, make some accommodation to the new technology. They abandoned the brightly colored cloth and shiny buttons of soldiers' uniforms and dispersed infantry on the field. But these changes were insufficient to alter the advantage of the defense in war.

Improvements in basic gunnery had also a great impact on the navies of the great powers. The developments of field artillery—rifling and breechloading especially—were widely applied to naval gunnery after 1860. Within 25 years, gun weight increased 23 times in the British navy, and the use of revolving turrets allowed much more flexibility. Rifling made it possible for a naval shell to pierce 34 inches of wrought iron at 1,000 yards by 1880. Increased range and impact of naval guns was matched by larger ships and thicker armor. In the 20 years after 1860, the thickness of armor increased from 4.5 inches to 24 inches.

These trends rapidly made older ships obsolete, vastly increasing the cost of naval competition for any country hoping to become or to remain a great power. But new military technology also made it easier for new powers like Germany, Japan, and, of course, the United States to enter the competition in rough equality with the older naval powers of France and especially Britain. The United States had no modern warship until 1883. In fact, for years after the Civil War the US navy opposed the building of iron ships. But from the 1880s, the United States, Germany, and Japan could enter the naval arms race without Britain's decades of accumulated warships. The addition of these new powers into the navy game accelerated the pace of technological innovation.

The American A.T. Mahan warned in 1884 that naval power designed to blockade enemy commerce was essential if a nation wanted to be a world power. Mahan claimed that naval blockades depended upon the ability of a massive fleet of battleships to prevail in concentrated battle over the enemy. Although this concept was a throwback to the era of sailing ships, it defined naval planning everywhere until World War I. This doctrine accelerated the rush to make more, larger, and faster battleships with heavier, longer-ranged guns.

The naval arms race culminated in the British Dreadnought of 1906, a ship of 21,000 tons equipped with ten 12-inch guns with a range of eight miles. Its state-of-the-art steam turbine engines were capable of speeds of 21 knots (24.27 MPH). All other great powers immediately followed suit. By 1913, the United States, with Teddy Roosevelt's prodding, had built 'Dreadnought' class battleships. Crash navy programs in Germany threatened English claims to 'rule the waves,' and a similar naval buildup in Japan helped that Asian power defeat a Western nation, Russia, in 1905. Technology accelerated the pace of military spending: Cost overruns, deficit spending, and rapid weapon obsolescence anticipated a familiar pattern in the recent nuclear arms race. British naval budgets rose almost 500 percent between 1884 and 1914, compared to scarcely 76 percent for the British army.

These battleships represented the power of nations seeking to show their muscle to the world. But they were hardly floating castles. Instead, they were vulnerable to relatively small explosions beneath the water line (because of the ocean's water pressure); they could be destroyed by the lowly mine and torpedo.

Mines were first used extensively by the Confederates against the Union shops trying to enter Southern rivers. But the first truly self-propelled underwater bomb was invented by a Scotsman, Robert Whitehead, in the 1860s. By 1900, the torpedo had a range of eight-hundred yards. Small, but fast and versatile, torpedo boats were commissioned to launch these weapons. Naturally, they threatened the huge and increasingly expensive battleships that were at the core of the naval arms race. Navies responded in the 1890s with the torpedo boat destroyer, a vessel that shared the speed and maneuverability of the torpedo boat but was also armed with guns sufficient to keep these 'pests' out of range of the battleship.

The torpedo was too potent a weapon to be defeated so easily. Arms inventors had long experimented with submersible attack weapons. Only in 1863 was a practical submarine developed in France. A self-propelled torpedo using compressed air as a propellant appeared in 1866. But the submarine became practical only with developments in the electric battery and motor (for underwater propulsion) and the gasoline and later the diesel engine (for movement on the water's surface). The Irish inventor, John Holland, brought these innovations together in 1896. His submarine, equipped with torpedoes, was quickly adopted by all the major navies. In 1903, the essential periscope (for viewing the surface when the submarine was submerged) was added. In time, submarines and mines threatened the very rationale for the battle fleet by making it difficult for these mammoths to get close enough to each other to engage in the 'decisive' duel as in the past.

By 1900, all thoughtful observers should have seen that weapons innovation had revolutionized war. J.S. Bloch's *The Future of War* (1902) predicted that mechanized war would lead to a bloody stalemate, but few paid any attention. Easy Western victories over mismatched Asian and African forces reinforced European thinking that the key to victory was offensive firepower.

Joining Technology and Total War, 1914–1918

World War I broke out on 4 August 1914 and ended on 11 November 1918. On both sides, it cost about ten million lives in combat compared to the 2.5 million soldiers killed during the fifteen years of the Napoleonic wars. Like the Civil War, World War I combined offensive battle tactics with a military technology that favored the defense, which contributed to the carnage. The war of 1914–1918 also was a continuation of the post-1870 arms race, with the rapid development of new weaponry, sparked by the dream of 'war-winning' technology.

Both sides expected that the war would end quickly in glorious victory just as it had for Germany in 1870. German strategy in 1914 involved invading France through Belgium, thus avoiding strong French troop concentrations on the French-German border. But the Germans failed to turn the French flank at the battle of the Marne in September of 1914. The result was a rapid extension of the battle line along a six-hundred-mile front. The advantage of the defense soon became apparent. When entrenchments, barbed wire, and cement-hardened gun bunkers were built on both sides, the devastating results of an attack became apparent. Any assault 'over the top' of the trenches resulted in mass slaughter by machine gun fire. Even so, most deaths resulted from artillery. Often artillery was used to soften enemy positions in preparation for an infantry attack. This tactic, of course, only warned the defender where to reinforce when the attack came. The results were deadly: In 1916, the German offensive at Verdun produced nearly a million casualties, while the Allied attack in the battle of the Somme raised that figure to 1.2 million killed and injured. Both battles ended in draws.

A generation of frantic shipbuilding was based on the expectation of a decisive naval battle. This too failed to happen. The only major battle of the Dreadnoughts occurred at Jutland in May of 1916, with inconclusive results. It only led to the retreat of both German and English navies to safe waters, though the British navy succeeded in blockading German ports from the beginning of the war, causing shortages of food as well as war supplies that led to the starvation of an estimated 424,000 Germans. German U-boats also attempted to blockade Britain by attacking merchant ships loaded with war supplies (and sometimes civilians).

Given the frustrations of stalemate, the search for a breakthrough weapon began almost immediately. Indeed, the arms race inevitably accelerated during the war. There were, of course, vast improvements in the number, size, and range of machine guns and artillery. The Germans, for example, built a hundred-foot-long 'Paris gun' capable of firing a shell 75 miles (reaching the French capital from behind German lines). But these advances did little more than terrorize civilians and increase the pace of killing on both sides. The German chemist, Fritz Haber, developed a chlorine gas attack that surprised the British in April of 1915 at Ypres. Although generally successful, the Germans were ill-prepared to take advantage of this surprise gas attack. The Allies wasted little time in issuing gas masks. In any case, prevailing winds favored the Western side; and the allies quickly learned to retaliate in kind. Haber later developed mustard gas (which burned the skin and lungs), and other gases that attacked the nervous system. Yet chemical warfare was relatively ineffective. It caused injuries, great pain, and was psychologically terrorizing; but it led to relatively few deaths. So devastating, however, was its psychological impact, that even Hitler (a gas victim in World War I) did not revive it in World War II. Many German officers were embarrassed by its use. It was so 'unchivalrous,' not a heroic way to kill or die (Figure 11.5).

The search for a war-winning technology continued. German advances in submarine technology just before the war seemed to offer a decisive advantage. Their U 19s had a range of five thousand miles from port. German submarines especially threatened British commerce. Some historians argue that only American protests in 1915 against U-boat attacks on neutral ships saved the British from being cut off from critical supplies and perhaps defeat. However, by the time the Germans decided to resume 'unrestricted' submarine attacks on 1 February 1917, the technological advantage had shifted to the defense against submarines. By then hydrophones could detect submarines; depth charges catapulted from decks of destroyers terrorized the U-boats; antisubmarine mines bottled up the German subs near their home ports; airplanes and dirigibles located submarines; and, in some cases, radio was used to direct destroyers to attack German U-boats. By the end of 1917, more German submarines were being destroyed than built. Clearly, this war-winning weapon had failed. Instead, unconditional use of German subs, including attacks on American ships, led in April of 1917 to the American entry into the war.

Figure 11.5 Soldiers training to go 'over the top' at the Battle of the Somme during World War I.

Credit: *Courtesy of Imperial War Museum via Wikimedia Commons.*

Ultimately, greater advantage was gained in two adaptations of the internal combustion engine, the airplane and the tank. Even before World War I, the great powers had experimented with using airplanes for reconnaissance, machine-gunning infantry, and bombing. But the Germans were the best prepared in 1914, with twice as many serviceable aircraft as Britain and France. When, in 1915, a synchronizing gear allowed a pilot to fire a machine gun through the propeller, the age of the air fighter had come. The result was a curious marriage of advanced technology and romantic images of 'jousts' between courageous and chivalrous knights of the air. Even though the life expectancy of fighter pilots was scarcely six weeks, the air corps attracted ex-cavalrymen, as well as eccentric race car drivers like the American Eddie Rickenbacker. The German "ace," Manfred von Richthofen, known as the 'Red Baron was a hero to both sides. Those who entered World War I with romantic ideals apparently needed to believe that war could still consist of contests between individual heroes—even if aided by technology. Still, few soldiers could forget the reality of mechanized killing and the drab life in the trenches. In any case, these airplane duels were essentially sideshows.

For some military strategists, bombing from the sky offered another way of breaking the armed stalemate: The Germans used both the hydrogen-filled dirigible (even if it was extremely vulnerable to attack) and Giant and

Gotha airplanes for bombing military and civilian targets. In anticipation of the German Air Force's massive bombing of World War II, some eighteen hundred British civilians died between 1914 and 1918 from German bombing. But, again, the technological advantage of one side was quickly overcome. By 1918, the allies had gained predominance in the air: They used some two thousand planes to throw back the Germans on the western front in an important offensive in August. However, it was a generation before the full military potential of combining air and land assaults was realized in Hitler's Blitzkrieg or 'lightning war' from 1939 to 1942 against Western Europe and the Soviet Union.

As important a technological breakthrough was the tank. Developed by the English Ernest Swinton in 1915, the tank was at first little more than an armored caterpillar tractor equipped with guns. Its advantage was its ability to surmount the problem that had bedeviled the offense since the Civil War—crossing the killing zone that had grown longer and much more deadly with rifling and machine guns. Despite resistance from the 'brass,' Winston Churchill managed to fund development of the tank. Its use in battle in 1917 proved successful in overcoming wire and other impediments as well as machine-gun fire; it was even more impressive in August 1918, when 450 tanks broke through at Amiens, France, capturing 28,000 Germans. But the tank was not used in sufficient number, nor supported by enough following troops, to become the 'decisive weapon. In any case, it remained vulnerable to breakdown and fuel shortages. As with the airplane, the tank would prove its ability to end the age of trench war only in 1939 and 1940 when Germany quickly dashed any expectation of a repetition of World War I's trench fighting by rapidly defeating Poland and France. Tanks were widely used by the Germans in the Soviet Union in 1941 and by the Soviets in throwing the Germans back in the following years (Figure 11.6).

Allied victory came in November 1918. It was nowt the result of a 'war-ending' weapon. Triumph was linked to technology, but in a more general way—especially to the industrial capacity of the United States. In 1914, the allied share of global industrial capacity without the United States was 28 percent, as compared to the 19 percent of the Central Powers. But when the United States was added in April 1917, the allied advantage was increased to almost 52 percent of world output. While German industrial output had dropped to 57 percent of its prewar level by 1918, the full weight of American productivity was brought to bear in the final year of the war. Despite the fact that Germany was at war 2.85 times as long as the United States, total American war production was 86 percent of that of the Germans. Americans had a huge advantage with their factories and machine tools designed for the mass production of consumer goods that were quickly turned to the war machine. This advantage was even greater after 1942 in World War II when the US joined Britain and Russia to liberate Europe from the Nazis and East Asia from Japan. As we shall see in a later chapter, this came ultimately with the full realization of total war in the dropping of the atomic bomb on two Japanese cities.

Figure 11.6 An American tank crossing a trench toward German lines in World War I.

Credit: *Courtesy of Library of Congress Prints and Photographs Division.*

The devastation and 'totality' of modern war was not merely the result of technology: Nationalism and other ideologies have mobilized mass armies—and whole societies—for contests that could end only in abject defeat or conquest. By World War I, wars had become battles between nations and ideas, rather than merely contests between armies. The result was that the soldier and battlefield were no longer isolated from citizen and country. Even the fundamental distinction between war and peace was eroded when the 'cold wars' of arms races increasingly dominated industrial life from the 1880s. Together, these trends marked the beginning of total war: The destruction of battle extended from military targets and soldiers to cities and civilians; war (and its preparation) became the business of industry and science (including the universities) as well as the military.

Trends that we have outlined in this chapter will be fully realized only during World War II with large scale aerial bombing and the nuclear arms race that followed. But the merger of the military, industry, and technology was fully evident in World War I. The tragic results of this war were in part due to the difficulty of soldiers and politicians to understand and adapt to military innovations.

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12 The Impact of Technology on Women's Work

Technological innovation had a dramatic impact on women at work—both in the home and in the labor force. Nevertheless, traditional gender roles shaped how technological innovation affected women's lives. Until very recently, labor-saving devices had not reduced the working hours of homemakers, even if they changed how women spent those hours. Equally, new machinery in the factory and the office did not merely neutralize the slight advantage of the average male in physical strength and thus offer women an equal playing field in competition for jobs. Instead, gender-role stereotypes long confined women's employment opportunities to a narrow range.

As discussed in Chapter 2, the colonial wife's work within the confines of the home environs combined both child and family care with activities that wage earners do today. Her work was heavy, repetitive, and prolonged; and her pressing responsibilities to churn butter, spin flax, and sew clothes limited the time and effort she could devote to childcare and the home. She was recognized as a skilled contributor to the family's needs in many ways.

Industrialization removed many of these 'productive' activities from the home and from most women. This was especially true for the more affluent wives in Victorian America, who became specialists in child- and home-care duties. Their households no longer were centers of production but rather of consumption and nurturing. For the women of working-class families, however, this change often meant that women followed the spinning machine out of the home and into the factory. For them, the separation of home and paid work raised often insuperable difficulties: it made nearly impossible the traditional combination of child- and home-care duties with wage earning. Thus, many of these women would abandon 'outside' work when they had children.

This is obviously an overgeneralization. Late-nineteenth-century married women often kept jobs in the textile mills; they sometimes worked in the carding rooms, for example, with their young children. Others, especially in large cities, were able to continue to earn income by taking in laundry, boarders, or piecework (as, for example, in shelling nuts or assembling toys). Rural women often followed lives similar to our colonial wives, scarcely touched by the industrial and consumer revolutions. While 40 percent of single American women in 1890 were in the labor force, only 5 percent of married American women reported occupations other than homemaker. Apparently married women (and their spouses) saw the conflicts between home (and especially child) duties and paid employment to be unresolvable. Mechanization in the home thus merely redistributed work effort there, until large numbers of married women began to work outside the home (as discussed in later sections of this chapter).

Affluent wives raised standards of home decorating and childcare, and they began to demand both more comfort and increased social recognition for their work within the home. This led to the development of 'home economics' as an academic discipline by 1900. Home economists wished to raise the status of home and child care by establishing 'best practice' techniques; later generations of feminists would criticize them for supporting the idea of woman as homemaker. Working-class mothers tried heroically to make do with the income of their husband (and very often of their older children). When possible, these women attempted to adopt the new middle class's ideas of well-appointed homes and improved childcare. These mostly nineteenth-century changes tended not to liberate women from home and traditional gender stereotypes but to reinforce and even narrow them.

New technologies were usually developed by men, because various barriers kept women from gaining the appropriate education, owning property, or being able to work outside the home, thus limiting women's innovative role. It would be a mistake, however, to view women as passive recipients of technology. Women appropriated technologies designed with men in mind (such as the telephone, phonograph, and bicycle) for their own use. In other cases, women encouraged changes in design: the electrical utility industry in particular actively sought advice from women regarding household appliances. Though at first suspicious that women were rejecting new technology on irrational grounds, they came to appreciate that women had legitimate concerns about whether particular technologies were worth the money.

The Corning Glass company employed well-known home economist Sarah Tyson Rorer to display their Pyrex cookware; she advised company executives on popular sizes, shapes, and properties. The company found her recommendations so useful that they retained her as a consultant. In 1929, Corning hired Lucy Maltby, a PhD in home economics, to head a test kitchen that sought to both educate consumers on how to use the new cookware and provide insight into product development.

The Mechanization of the Home

Long before the appearance of electrical gadgetry, the household was being transformed. Wood stoves, which required strength—generally male—to chop and haul wood, were gradually superseded in the nineteenth century by coal stoves. The replacement of open fireplaces by cast iron stoves using various fuels was complete only late in the nineteenth century. Urbanization and increased concern with public health encouraged the introduction of running water, beginning in urban areas, from midcentury. This was a slow process, first benefiting the affluent and urbanized, and much later working-class and rural families. As a result, countless hours of woman and child labor in fetching water was eliminated, transmission of typhoid and other diseases significantly reduced, and standards of personal cleanliness radically enhanced. Running water and the water heater made possible frequent bathing and clothes washing: only then was the traditional Saturday bath, in which a whole family would share the same tub of hard-to-get water, replaced by modern habits of personal hygiene.

Even more dramatic was the introduction of electric power to the home. Begun in the 1880s in urban areas with direct current, from the late 1890s alternating current spread across the land, electrifying half of American homes by 1920, and almost all urban dwellings by 1930. Nearly all rural households received electricity in the 1930s, thanks in large part to government efforts. Electrification made possible the mechanization of almost all facets of housework.

Already in the 1890s, the simplest domestic devices were powered electrically, although relatively few consumers could or would avail themselves of these. The electric iron emerged in 1893, although the adjustable thermostat did not appear until 1927. The electric kettle soon followed though internal heating elements became available only in the 1920s. Electric toasters, hotplates, and waffle irons also appeared in the early years of home electrification and were steadily improved in successive decades. The first bulky vacuum cleaner for use by professionals was introduced in 1901, and Hoover followed in 1908 with the first vacuum for home use; by the end of the 1920s, almost half of wired households would possess one.

The 1893 World's Fair in Chicago stimulated great interest in the potential of the electric household. Electric utilities encouraged innovative efforts in the ensuing decades. Even so, we should not exaggerate the victory of electric appliances. As late as 1923, 80 percent of home electricity provided illumination and 15 percent was devoted to ironing. One reason for the dominance of lighting was that in the early decades other appliances had to be either plugged into light sockets or wired directly. The modern two-pronged plug and wall receptacle emerged only slowly; it wasn't until 1917 that manufacturers agreed on a standard plug (Figure 12.1).

Many appliances posed much greater technical difficulties than the iron or toaster. In the case of the washing machine, early attempts to duplicate the rubbing action of hand washing were unsuccessful. The agitator was first developed for use in large commercial laundries, before being adapted to smaller home-machines. The first electric machine for home use appeared in 1914 (and was followed in 1918 by granulated laundry soap designed for machine use). One-third of wired homes possessed one by the end of the 1920s.

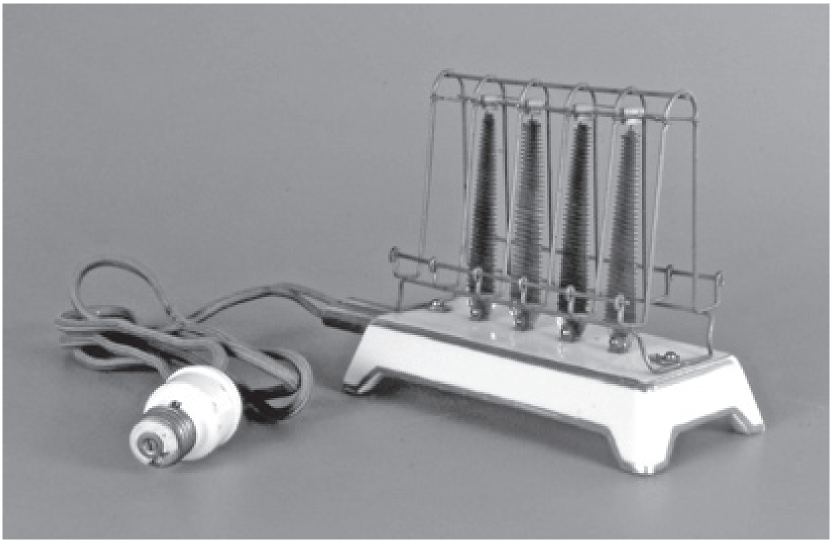

Figure 12.1 Electric toaster with lightbulb socket plug, 1909.

This machine could have been adapted to industrial use alone, thus removing a traditionally onerous task from the household, but it became instead primarily a domestic appliance. This may reflect a widespread desire for the convenience of home laundering. The development of a domestic washing machine may also indicate an unwillingness of Americans to abandon traditional expectations of what women should do at home. Laundry became much less laborious with the development of the automatic washer in 1935–although few households had them until the 1950s.

As was the case with lighting, competition from gas delayed the advent of the electric stove. Indeed, as gas companies lost their lighting market, they aggressively pursued opportunities in cooking and heating. Already in the late nineteenth century, gas ovens had reached an advanced state. By the end of the 1920s, there were almost twice as many gas stoves (14 million) as coal and wood combined (7.7 million). There were less than one million electric stoves by that time. Improvements in range elements–especially the nonoxidizing nickel-chromium alloy of 1908–were followed in the 1930s by the thermostat to control oven temperature, the one-piece all-steel body and significant advances in enameling. Despite the Depression, annual sales of electric stoves would number in the hundreds of thousands in the late 1930s.

The refrigerator was the last of the major household appliances to be electrified. The principle that the expansion of certain gases could cause cooling had been recognized since the eighteenth century; this type of refrigeration had been standard on ships and in butcher shops since the mid-nineteenth century.

Naturally, producers began to experiment with home refrigerators as electricity entered the home, and a handful of models were on the market in the 1920s. As with stoves, gas power was an alternative to electricity. Manufacturers of electrical appliances poured much more money into research and came to dominate the market in the 1930s. We cannot know what lay down the path not traveled but should note that many believed that gas-powered refrigeration might have been a superior technology.

Small-scale refrigeration presented numerous technical difficulties that delayed its adoption. The toxic refrigerants in use, especially ammonia, could not be applied safely in the home: a hundred patients had died in a Cleveland hospital in 1929 from exposure to such a refrigerant. This was the central reason that only 15 percent of wired homes had an electric refrigerator at that time. Chemists found a safer alternative in a fluorine compound called 'Freon' in 1930 (atomic theory had suggested that fluorine would be neither toxic nor flammable). About the same time, appliance producers developed the hermetically sealed motor and box, all-steel frame, better thermostats, and improved enameling. As a result, half of wired homes had an electric refrigerator by 1937.

Mechanization Outside the Home

Housework was transformed further by the purchase of previously homemade goods, as urbanization and improved transport systems made their mass production and distribution feasible. The most obvious example is clothing. The advent of the sewing machine did not necessarily remove garment making from the home, for it was as much a domestic as an industrial machine when first introduced. Elias Howe patented the sewing machine in 1846; in 1860 more than one-hundred thousand were produced in the United States. Isaac Singer popularized the sewing machine with clever marketing appeals to middle-class wives (deluxe showing rooms suggested that the well-appointed home was equipped with a Singer sewing machine). Singer also offered an installment purchase plan to ease the high price of a hundred dollars or more. When paper patterns became available in the 1870s, women at home could keep up with the latest fashion wherever they lived. Nevertheless, sewing technology also encouraged the commercialization of garment making. Late-nineteenth-century innovations such as machines to cut and press cloth, to sew buttonholes, and to sew on buttons helped tip the balance toward market production. Men's clothing (more difficult to make by hand), especially garments for single workers and sailors, were adapted more quickly to the ready-to-wear market than were children's and women's clothing. Over the course of the twentieth century, ready-made clothing steadily decreased in price while increasing in quality, fit, and range of styles. In 1894, the Sears catalog had no women's clothing; by 1920 it had 20 pages. The final victory of ready-made clothing came after World War II. Women continued to sew at home, but increasingly it became an 'art' rather than a necessity (Figure 12.2).

Figure 12.2 W.J. Morgan Sewing Machine Advertisement, 1882. Household appliances could serve to reinforce the woman's role as homemaker rather than liberate her.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

The home sewing machine was one of the first products to come with an instruction booklet (clocks and bicycles were others). These instruction booklets were often 20 to 50 pages in length. They described how to oil the machinery (once or twice a day!), change needles, thread needles, employ different stitches and fix or replace various parts. The earliest instructions were often terse and employed terminology with which the average person was unfamiliar. Over time, they became much more user-friendly. In particular, it became increasingly common to provide diagrams of complex tasks.

The modern food processing industry only gradually replaced home-prepared foods. The primary technical challenge was to extend the 'shelf life' of perishable foods. Canning—sterilization by heat within sealed containers, which were at first usually glass—was developed in 1809 to feed Napoleon's troops in France. Canning would revolutionize the way humans consume food but has received far less attention from historians than other technologies, perhaps because it involves a host of small improvements over a period of many decades. Metal cans appeared in 1839, and machines were patented for stamping the sides and tops of cans by mid-century, followed in the 1850s by devices for soldering the two parts together. It was 1883 before the first automatic can-making factory opened. The modern can opener appeared only in 1875; consumers had previously had recourse to tools such as chisels. In the 1850s, Borden made its name by canning evaporated milk (allowing milk to be transported long distances for the first time), but Heinz and Campbell became household names with their varieties of canned fruits, vegetables, and soups only in the 1880s and 1890s. Machines were developed about that time to peel peas and corn, and process salmon. Cans were improved as well. In 1905, the sanitary can was designed in which sides and top were cut to fit snugly together. In 1908, the development of a sealing compound that could maintain a hermetic seal rendered soldering unnecessary. By the 1920s, enamel coatings prevented the food from reacting with the tin, thus preserving both food taste and color. In particular, this made it much easier to can meat; canned pork output doubled between 1924 and 1925. The output per minute of can-making machines almost doubled in the 1920s. As cans were improved, new products, such as baby food, syrup, and tomato juice, were canned. In the 1930s, the difficulties inherent in canning liquids with expansive properties, such as beer, were solved. The more severe corrosion and expansion problems of canned soft drinks were overcome in the 1950s. Previously there had been a slow development of bottles and bottle caps for soda drinks through the nineteenth century; critical innovations in both glass-blowing and the crimped bottle cap in the 1890s allowed soda to become a mass market good.

Public acceptance often lagged behind technical feasibility for some years. Producers had to address health concerns as well as more subtle questions of taste; many traditionalists objected to food not produced by homemakers. Widespread use of canned foods in both World Wars was of great importance in overcoming public resistance. Firms used advertising and sometimes encouraged government regulation of production processes to assure consumers of the safety of their products. Twenty-first-century concerns regarding the health impact of many ingredients in processed foods suggest that twentieth-century consumers may have been too trusting of processed foods.

Canning necessitates heating, and this has undesirable effects on the taste of some products. Freezing, while less successful in killing microorganisms, has superior taste characteristics for a range of foods. Clarence Birdseye had begun experimenting with freezing foods after a trip to Labrador in 1915. By 1929, he had discovered that fast freezing caused smaller ice crystals to form, and thus did not physically damage food as when it was frozen slowly. General Foods released the first line of frozen foods based on his patent in 1930. Although this date coincides with significant achievements in refrigeration, the market was limited for years by insufficient freezing space in both stores and homes. Separate freezing compartments were only added to home refrigerators as frozen foods entered the market. There were only some five hundred stores with freezers nationwide in 1933, but 15,000 stores had them by the end of the decade. Beginning with frozen vegetables and juices, producers gradually added various prepared foods in the 1940s. 'TV dinners' were introduced in the early 1950s, not long after the successful commercialization of television itself.

Before canning and refrigeration, perishable foods had to be consumed locally. This meant that consumers rarely experienced foods from other climates, and only consumed local foods seasonally. These technologies thus expanded dramatically the range of food options that consumers possessed. They also eased the challenges of home cooking, though consumers only slowly appreciated this potential. Homemakers could serve Campbell's soups rather than making soup from scratch. Campbell's and other companies decorated their cans and spent vast sums advertising the quality and ease of use of their products to national audiences–and studying consumer reactions to this advertising. As new technologies emerged and public attitudes toward home cooking slowly changed, firms marketed a host of prepared foods. These served to change attitudes toward home cooking further.

The 'Changing' Role of Women in the Home

The mechanization of the home, along with ready-made clothing and factory-processed food, eased women's work in many ways. American families could also achieve higher standards of cleanliness, more fashionable clothing, and more varied diets the year round. Doubtless many were healthier and happier as a result. Nevertheless, the effects of all this modern technology on time spent on housework by women has been much less revolutionary. Even though technology eliminated some of the worst chores—such as washing clothes by hand—such duties have tended to be replaced by new household tasks, especially in the early twentieth century. Time spent in housework by women fell by only six hours per week between 1900 and 1965 but fell another 12 hours per week between 1965 and 2005 (but housework by men rose 13 hours per week over the century, despite the decreased need for traditional male tasks such as wood chopping and leatherwork).

Why did time spent on housework not fall faster? Servants, once common in middle-class households, largely disappeared in the interwar years due in part to the introduction of labor-saving devices (such as the washing machine). There was also a decline in the supply of women willing to do that sort of work, in part because of immigration restrictions from 1924 and alternative opportunities for working women. The middle-class homemaker found herself removed from adult company for much of the day (washing, in particular, had previously required cooperation between homemaker and servant). Perhaps these mechanical aids were a more positive blessing to working-class women.

There were various responses to these new technologies. To many, the mechanization of the home seemed to undermine the need for homemakers. Feminists such as Charlotte Perkins Gilman argued that this trend was to be applauded and women should follow the path of men and become members of the workforce. The homemaker, she claimed in 1898, had become irrelevant. This was a radical minority view in the 1900s, however. Christine Frederick espoused a much more common opinion that women's domestic role should change but be maintained. Women, Frederick argued in 1920, should become 'domestic engineers,' engaged in machine-aided work in the home that paralleled that of men in factory and office. Women's domestic work should become efficient by making the most of the new domestic technology, but women should remain in the home (the attempts of Frederick and others in the home economics movement to apply scientific management [see Chapter 13] to the home were largely unsuccessful). A decade later Frederick maintained that the 'new' homemaker had become the principal consumer in the home, and merchandisers should appeal to her purchasing power through advertising. Popular women's magazines encouraged this ideal of the modern homemaker as a 'domestic engineer' and a skilled consumer who had abandoned the old ways of drudgery. Glossy pictures and promotional articles by noted home economists lent a certain glamour and authority to the task of housekeeping. Some argue that this revitalization of the homemaker in the mechanized home reflected the unwillingness of Americans (males especially, perhaps) to abandon the expectation that 'a woman's place is in the home.' Some might go further and suggest that this ideology in the consumer age benefited manufacturers of home-related goods. Though later feminists would be critical of them, home economists were trying to elevate the status of women by glorifying housework. Commercial laundries and cooked-food delivery services were two possibilities that feminists advocated early in the twentieth century, but which failed in the face of the ideal of the homemaker. The domestic washing machine, by contrast, fit this notion of the 'new' homemaker.

In any case, with the decline of old domestic duties, the twentieth-century homemaker emphasized higher standards of both cleanliness and cookery. Running water and indoor plumbing could make lives easier in many ways, but also encouraged additional work in cleaning bathrooms. Washing of clothes, previously Monday's task, was now performed several times a week. With vacuuming, the era of the carpeted home became possible, even if vacuum cleaning was perhaps more time-consuming than sweeping the wooden floor with a broom. In the kitchen, the revolution in appliances, along with access to a broader range of better-quality (often processed) ingredients, freed time for experiments with flavor and concerns with nutrition. The new cooking also required more time to plan meals and more dishes to wash than was demanded by the stew dinners of an earlier era.

As the need for carrying water and sewing clothing declined, women shifted much of their time to improved child rearing. From the 1910s, educators, government agencies, and advertisers suggested that the 'good' mother did not spend time performing tasks that electricity could do for her, but rather devoted that time to her children. Even access to the family car did not save the mother time. It often simply increased her duties; she chauffeured her children to school, ball games, and piano lessons. Women also came to devote more time to shopping. Services such as home delivery by grocers declined gradually in the twentieth century with the growth of the 'self-service' supermarket. The increasing range of consumer choice, coupled with the enhanced mobility accorded by the automobile, encouraged hours of investigating shopping options and endless trips between stores in search of 'bargains.'

Thus, for all of these complicated reasons, labor-saving technology did not much reduce the hours of labor required of homemakers. Most decidedly, these mechanical innovations did not directly liberate women from the home and free them for work in the paid labor force. Only after 1945, and then slowly, would married women enter the labor market. This trend was prompted by new economic and social conditions that were only indirectly related to technology (see the following discussion). Even so, there was a considerable reduction of drudgery with the reallocation of domestic work. This improvement must be balanced by the fact that homemaker's labor became an increasingly isolated and, for many, lonely experience. Reliance on complex technology has perhaps also led to the same sort of alienation that plagues the modern assembly-line worker. Prepared foods have many excellent qualities, but cannot yield the same pride in artisanship as, say, baking a cake from scratch can.

Technology and Women at Work

If domestic technology did not lead to a fundamental transformation of the homemaker's role, perhaps machinery in the office or factory had a more significant impact on women's lives. An excellent innovation to explore in this regard is the typewriter. A printer from Milwaukee, Wisconsin, named Christopher Sholes was among the first to develop a practical mechanical typing machine in 1867. He sold the rights to the device to the arms maker Remington in 1873. The development of the typewriter coincided with a vast expansion of the demand for clerical workers in banking, railroads, commerce, and government, reflecting, in turn, the growth in the size of corporate hierarchies discussed in Chapter 10. Although some had feared that typewriters would put clerks out of work, employers' appetites for recording information expanded much faster than the cost fell (as happened in the computer age). Carbon paper, addressing machines, calculating machines, cash registers, mimeographs, and dictaphones were also important innovations

Figure 12.3 Typing class, Aquinas High School, Bronx NY, c. 1940.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

that accompanied this growth of the office. The clerical sector, which had employed less than 1 percent of the labor force in 1870, grew to account for 10 percent in 1930 (Figure 12.3).

The entry of women into the office facilitated much of that growth. This was by itself something of a cultural revolution. In 1870, working with and serving the public was considered in many quarters to be 'unladylike,' and an occasion for inappropriate sexual encounters; 95 percent of clerical workers were men. The typewriter, however, was a 'sex-neutral' machine—that is, it was associated with neither men nor women. Some would argue that women were especially appropriate for its use because it required manual dexterity, and women were widely assumed to excel in this skill given their previous dominance of sewing. It was also rather like playing the piano, a practice that many 'genteel' women learned as children. However, the first typists were men; when women first entered typing schools, many scoffed and suggested that typing would forever remain a male domain. Nevertheless, by 1930, women constituted 95 percent of American 'secretaries.'

The typewriter emerged as the changes discussed earlier were potentially freeing women—first daughters and later homemakers—from work in the home. Educational attainment of women was also rising at the time, and there were few other jobs for women with high school educations to pursue. If clerical work had remained a male preserve, a shortage of applicants with the appropriate skills who would have been willing to work for the same wage would have slowed the expansion in clerical employment. Faced with this pressure, social attitudes opposed to women working in offices began to erode.

Did this flood of women into the office contribute to more economic and social opportunity for females? Of course, clerical work was preferable to domestic or industrial labor for many young women: it was respectable and often less onerous. We must consider, however, how the position of secretary changed with the influx of women. Before the advent of the female typist, clerks had maintained a close confidential relationship with their employer, and secretarial posts often served as a stepping-stone to management. Indeed, some high-status positions of *personal* secretary to top business executives would continue to play that role and would remain dominated by men. The expansion of the office led to the division of clerical labor, creating the typing pool and filing room. Women were assigned these more repetitive and less responsible jobs. Moreover, as women came to dominate the secretarial occupation, the pay decreased relative to other positions where males predominated. Employers expected female secretaries to quit soon after marriage. This encouraged managers not to train women for more responsible posts and justified low wages. Such salaries gave women little incentive to remain. In the twentieth century, the job expectations of employers sometimes resembled that of a 'substitute wife.' By the 1910s secretaries were expected to prepare coffee, cover up the boss's indiscretions (with his spouse and superiors), and listen sympathetically to his side of the story.

Technology has encouraged the entry of women into previously male occupations on a broader front by reducing the importance of physical strength. Forklift trucks and conveyor belts do much of the lifting and carrying previously done by hand. The employment of women in road construction became more likely as bulldozers and graders replaced picks and shovels. Still, the evolution of social attitudes played a more significant role. Women flaggers have become a common sight on road construction crews only in the last decades—and this is still by far the most likely place to see them—although the physical demands of the job have scarcely changed. Likewise, more women have entered professions such as medicine and law, but this is due to social rather than technological changes.

The Demand for and Supply of Female Labor, and the Persistence of Housework

Housework and gender stereotypes in the workplace have persisted despite technological change. This does not mean that there have been no changes in these areas. The most dramatic trend is the rise in the percentage of married women in the labor force in the twentieth century, and especially after World War II. Many single women, of course, worked for wages in 1900, following a pattern established even before industrialization separated workplace and home. The preferred family strategy of the working class in 1900 was to send older children to work to supplement the father's inadequate wages. Married women, especially those with children, usually worked outside the home only if the family's financial needs required it.

Labor force participation for women would peak at 60 percent in 1999 and fall a bit after that primarily because of decreased participation among young women pursuing advanced education (Table 12.1).

The reasons for this change are complicated. As we have seen, the mechanization of traditional household work by itself had little direct influence on the decision of married women to enter the workforce. A prevailing view is that World War II introduced women to the income and freedom that wage work brought, as women took jobs in factories while men were at war. The problem with this analysis is that immediately after the war men replaced most women workers in those jobs that had been traditionally male. In any case, in 1945 government, business, and unions were equally unwilling to provide the childcare and other support services necessary to convince many women that wage work was possible or desirable for them.

There are better explanations for women entering the workforce that are more subtle. First, we need to remember that public hostility to women entering many job categories created a segmented labor market, channeling women into a few 'feminine' professions in the clerical, educational, food service, and health areas. Married women were most unwelcome in many of these jobs. Even in the 1940s, women were often forced upon marriage to leave nursing and teaching jobs. Bans on the employment of married women in schools and clerical work effectively excluded most women from possibilities for promotion; this policy was motivated both by discrimination and fear that women would be less devoted to their firm because of familial responsibilities. During the Depression, a time when jobs were scarce, women, especially those who were married, were frequently banned from jobs that a man could hold, based

Table 12.1 Female Labor Force Participation (as a percentage of total female population)

Year	*Total*	*Single*	*Married*
1890	18.9	40.5	4.6
1900	20.6	43.5	5.6
1910	25.4	51.1	10.7
1920	23.7	46.4[a]	9.0
1930	24.8	50.5	11.7
1940	25.8	45.5	15.6
1950	29.0	46.3	23.0
1960	34.5	42.9	31.7
1970	41.6	50.9	40.2
1980	51.5	64.4	49.9
1990	57.5	66.9	58.4

Credit: Historical Statistics of the United States, from census data (to 1970), US Bureau of Labor Statistics.

Note that there were subtle changes in the way "labor force participation" was defined through time.

on the common belief that salaried positions should be reserved for 'breadwinners.' This attitude gradually relaxed as the demand for employees in these 'women's sectors' grew, and as the number of single women available proved to be inadequate. Thus, for example, in 1940, 87 percent of American school districts were unwilling to hire married women; a decade later, 82 percent were willing to do so because they found that there were not enough men and unmarried women to fill all the jobs. This happened slowly in many professions throughout the first half of the century. After World War II, the demand for women in clerical work, health, and education increased rapidly, in part from the demand induced by the baby boom for teachers and nurses, but also from rapid growth in private and public bureaucracies and the healthcare industry.

Other changes after 1945 encouraged married women to enter the workforce. As the baby boomers matured in the 1960s and 1970s, mothers increasingly entered the workforce to save for their children's college educations. Rising skill expectations obliged families to alter strategies—shifting supplemental earning responsibility from older children to mothers, to help pay for the training of these offspring. As well, traditional sources of supplemental income made by women—from taking in laundry, running small 'Ma and Pa' stores, and other home-based jobs—largely disappeared. Whereas a quarter of families had a boarder in 1900, only 2 percent did in 1920; potential boarders could now avail themselves of appliances and convenience foods and chose to live on their own. These essential contributions to household income could only be made up by women taking jobs (often, at first, on a part-time basis) outside the home. The upsurge in the 1960s may also reflect new family planning practices, especially the birth control pill (see Chapter 19), that freed women from child care at an earlier age. The rising rate of divorce from this period may also explain (and reflect) some of this trend. And, for young women, especially from the educated middle classes, the emergence of a new wave of feminism from the mid-1960s doubtless played a role in women choosing to delay or forego childbearing to pursue careers—or attempting to blend the two activities. Increased access to childcare has facilitated this task.

Another still more subtle factor helps explain this trend. The increasing range of goods—especially of consumer durables, such as cars and houses—that technology has put on the market may have changed attitudes toward the value of the homemaker's services. If the husband's income was insufficient to buy these new goods, then the couple might choose to forego the new high standards of homemaking by the wife's entry into the labor market. The rapid rise in home ownership from the early 1970s doubtless contributed to this trend. In the 1980s, it was common for one income of a two-career family to be devoted to mortgage payments.

Within the last two generations, we have witnessed the erosion of the nineteenth-century family division of labor, in which the husband brought home the money and the wife did all of the housework. As we have also seen, these 'traditional' patterns date only from the beginning of industrialization' when the workplace and home were separated. What has become of housework, now that in most families no one person devotes his (or, more likely, her) full attention to it? There has been a slow, but real, increase in the number of hours of housework performed by men, but women still perform most housework even in families where they work full-time outside the home. Total time spent by families on housework has fallen a little in recent decades, due in part to innovations such as microwave ovens and online shopping, but also increased frequency of eating out.

The new allocation of family time, however, has not been an unqualified success. Many two-income couples have experienced a 'domestic speedup' wherein the traditional realms of personal life—family care and leisure—are crammed into shorter periods of the week. Technology can help. However, childcare and many home maintenance jobs are difficult to mechanize. So are quality personal relationships. The television is a convenient babysitter, but not a substitute for parental interaction.

Technology has affected the lives of twentieth century-women in myriad ways. It has reduced the drudgery of household work, allowing women to shift their time to improved child and home care, and it has facilitated the entry of women into new types of jobs in clerical and other fields. However, the impact of technology is less direct and effective in reducing time devoted to household tasks and increasing women's status in the workforce. In the twentieth century, married women entered the labor market in massive numbers and increasingly entered management and the professions, but the impact of technology on these trends is indirect and ambiguous. Persistent social attitudes about gender roles, and conflicts between market and personal needs are also critical in shaping women's work.

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13 The New Factory

Technology in its broadest sense involves not just tools, machines, power sources, and chemical agents; it also includes the way in which productive activity is organized. New machines encourage changes in plant layout and organization, while organizational innovations pave the way for new machines. The thin line between these two forms of innovation is exemplified by the career of Frederick Winslow Taylor—a significant figure in the advance of both machine tools and 'scientific management.' In the 1890s, Taylor believed that if managers applied the same scientific principles that led to dramatic increases in the efficiency of machines to the activities of workers themselves, they too could become much more productive. This same close linkage between mechanical and managerial innovation characterized the introduction of Henry Ford's assembly line in 1913.

Taylor and Ford, both excellent at publicizing their achievements, insisted that they represented a new elite, based on practical accomplishments rather than inherited status or mere wealth. They claimed to champion harmony between workers and employers. In this, they were in accord with the Progressive movement of the time, which believed that the application of expert advice could alleviate society's many problems. Nevertheless, wage earners sometimes balked at being analyzed and organized like machines. Still, as we shall see, Taylor, Ford, and other proponents of scientific management promised and, in many ways, delivered much higher productivity, resulting in cheaper goods, higher wages, and more leisure than was otherwise possible.

Advances in Machine Tools

Interchangeable parts depended on the accuracy of the machinery employed (see Chapter 6), and thus the precision of the machine makers themselves. While the machine tool sector is small, it had (and continues to have) a substantial impact on productivity advances across manufacturing. Machine makers were limited in the early nineteenth century by the poor quality and high price of crucible steel (some forty times the price of iron rails per ton); machines were thus generally made of wrought iron or wood, with only cutting devices made of steel. As the cost of steel fell dramatically in the late nineteenth century, metallurgists focused on overcoming the inevitable imperfections introduced as the steel hardened. Machinery of all sorts would be severely limited in precision until cutting and grinding tools could overcome these imperfections.

Grinding machinery, using natural materials such as emery, clay, and feldspar, improved markedly in the nineteenth century. Where James Watt marveled at achieving precision within the width of a coin, machinists by the 1880s expected tolerances of a thousandth of an inch, and a generation later a tenth of that. In 1895, the opening of the Niagara power station made possible the economic production of silicon carbide in electric furnaces. This material, exceeded in hardness only by diamonds, soon replaced natural materials in grinding machinery and encouraged further machine improvement. The automatic high-speed grinder of the late 1920s alone increased labor productivity tenfold and proved invaluable to the bicycle, automobile, and airplane industries.

Alloy steels themselves revolutionized the cutting of steel. In 1868, after years of experimenting in England, Richard Mushet produced a tool steel from manganese-rich ore. There was limited use of this alloy until the 1890s, when Frederick Taylor, desirous of finding the capabilities, limitations, and optimal applications of machine tools in order to organize production more scientifically, performed more than fifty-thousand separate experiments involving cutting tools made of Mushet steel. He found improved efficiency by developing round-tipped (as opposed to pointed) tools and directing a water stream at the cutting area. He also replaced Mushet's manganese steel alloy with chromium and superheated tungsten, which increased cutting speeds four to five times. This latter discovery led to the complete redesign of machine tools. To take full advantage of the new cutting tools, machines had to have variable speeds and be powered by individual electric motors. Based on Taylor's work, a cobalt-chromium-tungsten alloy was introduced in 1917, which further doubled machine speeds, as did tungsten carbide in the 1930s.

The American machine tool industry had deviated from British practices by the mid-nineteenth century; the British arsenal ordered American machines in 1853. Encouraged by the size of the American market, American machine tool manufacturers developed special-purpose machines tailored to the needs of particular industries in the late nineteenth century.

While the steam engine and railroad had been the focus of engineering effort through most of the nineteenth century, the automobile industry drove developments in machine tools from the 1890s. Internal combustion engines and other car parts required much more precision than had steam power. When other machine shop operators proved hesitant to replace their entire capital stock with new machines, automakers became the key users and sources of improvements in those machines in the first two decades of the twentieth century. As noted in Chapter 9, the automobile industry championed the development of alloy steels; it also showed machine makers how the proper use of lubricants, gears, and bearings could enhance speed and precision while lowering maintenance. Airplanes, with their even greater technical requirements, would emerge as a further challenge to machine manufacturers.

Electrification, although not affecting precision directly, greatly enhanced the efficiency of industrial machinery. Rather than being connected to a central steam engine through a cumbersome system of belting, machines could be powered individually. Motor speed and power could be tailored to the needs of particular machines. The percentage of electrically powered machinery grew from 4 percent in 1899 to 30 percent in 1914 to 75 percent in 1929. Kilowatt-hours per worker rose from 1.2 in 1920 to 3.2 in 1950. Plants were redesigned to reflect the new power source (Figure 13.1).

A brief postscript to the preceding discussion: The American technological lead in machine tools would carry into the postwar period. The Air Force financed research that led to the first programmable or 'numerically controlled' machine tools. Punched tape gave way to microprocessors in the 1970s. While American industry, encouraged by the Air Force, focused on costly high-precision tools, Japanese producers identified a market for lower-cost multiple-use machines from the 1960s and became dominant in that market from the 1970s.

Scientific Management

Scientific management began with the first factories in late-eighteenth-century England. Charles Babbage, who we will encounter later as a designer of mechanical calculating devices, attempted to calculate the time that it took workers to perform various tasks in 1820. However, the method of scientific management (and the name itself) were only popularized by Frederick Taylor from the 1890s and became associated with his name.

Many factors encouraged renewed interest in organizing human work. The growth in the size of industrial firms coaxed employers to systematize operations (see Chapters 5 and 10). The gradual replacement of skilled artisans by relatively unskilled machine minders made possible increased managerial authority. At the same time, increased union activity and massive work stoppages (e.g., the Pullman and Homestead strikes of 1891 and 1894, respectively) encouraged industrialists to adopt new methods to reduce the power of workers. Scientific management can be understood in part as an attempt to wrest control of the pace and processes of work from skilled machinists and other artisans. Finally, as per-capita incomes rose steadily in the nineteenth century, increased productivity became a societal ideal, replacing in part older fears that changes in work practices would benefit employers alone. This view bolstered support for changes that raised output even when they also reduced the autonomy and skill of workers.

Frederick Taylor was born into a prominent Philadelphia family in 1859. Although he was well traveled and educated in his youth (and would earn a degree in engineering at what would later become the Stevens Institute of Technology), he also spent many years working his way up from apprentice

Figure 13.1 Belt drives for lathes and grinders, Thames Tow Boat Company, New London CT.
Credit: *Courtesy of the Library of Congress, Prints and Photographs Division.*

to manager of the Midvale steel company. In the 1870s, it was still common to become an engineer in this way. Although Taylor's family connections got him started at Midvale, he had a real mechanical aptitude (which, as we have seen, led to radical improvements in machine-tool steel). Taylor would also design shovels suited to distinct tasks. Early in his career, however, Taylor began focusing his attention less on machines and more on the workers tending them. His interest in optimal machine speeds transferred to a similar obsession with increasing the pace of human labor. Taylor said that the seeds of his interest in management were sown during his early and rapid rise up the firm hierarchy. He experienced firsthand the disorganized nature of firms of that time. Top management was often only loosely involved in actual production; factory supervisors wielded power to hire and fire their subordinates. They often abused this power to protect their friends, or to take bribes or kickbacks from workers. In the machinery industry, these supervisors were often independent subcontractors. Taylor encountered great difficulty in getting the workers to work harder. 'Soldiering,' working slowly to protect jobs and maintain high piece rates, was especially encouraged by older, less productive workers. The workers did not strike or overtly disobey him, but merely refused to pay attention. Laziness due to both peer pressure and natural inclination, Taylor came to think, was the principal roadblock to improved productivity. He shared with many employers the view that workers were limiting the advances in productivity inherent in new technology. He once maintained that two-thirds of labor time was wasted.

Taylor believed that increased efficiency depended upon breaking up the group mentality of workers and encouraging individual achievement with financial incentives. He disdained the hostility that often existed between workers and management. Taylor firmly believed that increased productivity would lead to higher wages and thus workers had an interest in cooperating with management to improve efficiency. At the same time, he opposed the practice of managers' immediately cutting piece rates as work speeds increased; he recognized that this eliminated workers' incentive to increase productivity and created mistrust between managers and wage earners.

Taylor offered factory managers many suggestions for improving output; these included better cost accounting, inventory management, and centralized planning of production in new 'engineering' departments. Importantly, Taylor urged the redesign of workplaces to minimize unnecessary movement of workers or materials. Yet Taylor is best known for his overriding principle that 'science' should be applied to the management of work—that rational rules replace custom. Taylor insisted on the 'one best way' of performing a job. This meant that management, rather than workers, should conceive of and design particular jobs. He ignored the experience and acquired skills of laborers. Of course, Taylor recognized that individual work capacities varied. He tended to rely on an increased work standard to separate the competent workers from the failures, rather than developing training programs or aptitude testing. His efforts to treat workers in the same manner as machines often ignored the problem of fatigue.

The element most commonly associated with Taylor is the stopwatch or time study. By timing the performance of tasks, he hoped to identify and eliminate wasteful effort. Even more importantly, management would learn just how much work a worker could reasonably perform, providing a 'scientific' base for setting piece rates. Workers sometimes wondered, however, how scientific time study was when Taylor selected the ablest and most motivated laborer to test. Once Taylor had calculated how much a worker should be able to accomplish in a day, he established differential rates, so that workers who approached this target earned more per piece than their slower counterparts. In one case, for a job in which workers had previously received 50 cents per piece finished and produced four or five a day, Taylor calculated that they should do more than twice that. He changed the rate to 35 cents per piece for ten or more per day and 25 cents per piece for fewer than ten. The incentive to finish the tenth piece was huge, and those who did not maintain that pace were often fired or quit. This system tended to divide workers into two groups: The younger, more financially motivated, and the older or less driven laborers.

An excellent example of Taylor's method is the way he handled a group of women working in the inspection department of a ball bearing factory. He noticed that they spent much of their time conversing with each other. Over a period of months, he put in barriers so that they worked separately; he introduced differential piece rates to encourage speedier work; and he laid off women who he believed could not maintain the pace. He also cut their working day from 10.5 to 8.5 hours (even though the women, fearing exhaustion from doing more work in less time, opposed this reform). He also introduced 'teachers' who visited inspectors who were falling behind and 'helped' them increase their pace. Taylor believed that he had done the workers a favor by both reducing their hours and increasing their daily income (while substantially reducing the firm's costs). He was especially proud of the lack of labor unrest. One might wonder, however, whether this was due as much to Taylor's success in dividing the workforce as it was a result of more pay and shorter hours.

Of course, Taylor's innovations were not unique, as he claimed, nor did employers embrace them uncritically. His piece-rate schemes (and his tendency to fire underachievers) were similar to the 'driving' methods of traditional managers. Even stopwatch studies were not new, and Taylor is remembered more for popularizing these than rendering them scientific. Taylor shared with many conservative business leaders the view that workers were primarily motivated by money. Like others, Taylor disdained the collective skills of workers and ignored their psychological and physiological limits.

At the turn of the century, Taylor 'retired': He spent the next fifteen years publicizing his techniques. His former assistants did the actual work of introducing scientific management to about two-hundred companies. These included not just industrial firms but department stores, railroads, steamship companies, banks, publishers, and construction. First, they attempted to improve plant layout and standardize machinery. Then they tried to centralize planning. Only then did they believe they could conduct proper time studies and set scientific wages. Because the existing managers were often antagonistic to Taylorist reforms that threatened their positions, Taylor's disciples often lost their contract before implementing the time studies. Even the plants that Taylor himself had reorganized tended to abandon his reforms within a few years. Here, too, changes in plant layout and machinery were what survived.

The Gilbreths and Motion Study

Despite the limited impact of his specific program, Taylor inspired many to develop and modify scientific management. While Taylor used time study mostly to establish piece rates, others would focus on the measurement and improvement of work methods. This led to motion study, the analysis of the body movements required to perform simple tasks. It aimed to decrease fatigue and increase productivity by finding the optimal movements needed per task. This method reflected the realization that money incentives alone were insufficient for increasing human output. Frank Gilbreth was a significant figure in this new approach to work efficiency. While watching bricklayers at work, he realized that they spent most of their time and energy picking up bricks and moving them into position. Gilbreth developed an adjustable table that raised bricks to the appropriate level, and the average number of bricks laid per hour increased from 120 to 350.

Gilbreth and his wife Lillian soon pioneered the application of the motion picture camera to motion studies. This allowed body motion to be traced in greater detail than could be accomplished with the naked eye. Slow-motion techniques ('micromotion') were especially valuable; they were widely adopted not only in industry but in the sporting world, where coaches could (and still do) use films to instruct athletes on how to perform at the top of their ability. The Gilbreths were anxious to show that their techniques had applications outside of the factory, and they conducted studies in homes and offices as well.

The Gilbreths invented cycle graphic analysis. By attaching small lights to the fingers and head of machine operators, and taking time-lapse photographs of them at work, they obtained traces of the movements of the hands and head during the elapsed time. By superimposing grids on the pictures, they could accurately measure the distance traveled by the body parts under study. They sometimes used chronocyclegraphic analysis, in which the light would flash at regular intervals; from this, they could measure the speed of particular motions (Figure 13.2).

Despite the availability of these sophisticated techniques, costs restricted most motion study to physical observation. Even here, the Gilbreths fine-tuned methods of analysis. For example, they identified 17 different types of hand movements, which they termed 'therbligs' (based on 'Gilbreth' spelled backward); these are still employed in management studies. One of these movements is 'search'—a wasteful motion that could be reduced by proper labeling or lighting. Motion study produced general principles designed to minimize fatigue—for example, both hands should start and stop simultaneously, a curved motion is superior to straight-line motion, and eyes should move around rather than being fixed on the same spot.

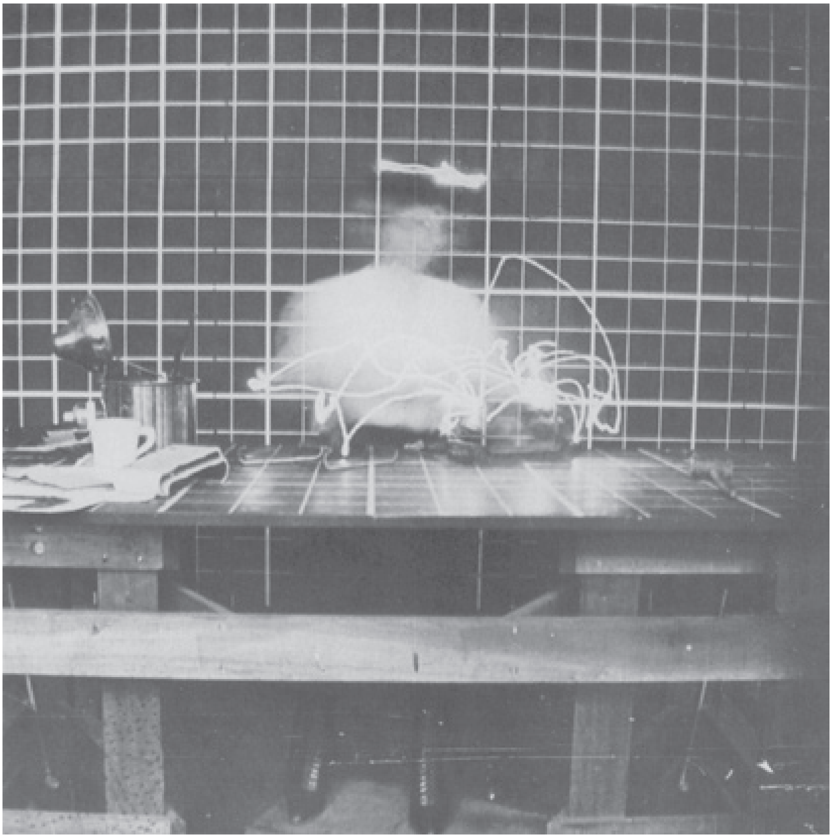

Figure 13.2 The Gilbreths' cycle graphic analysis. Lights on the head and hands trace the worker's physical movements. The grid lines were superimposed through double exposure of the film.

Credit: *Courtesy of the Smithsonian Institution.*

Gilbreth incurred Taylor's wrath for arguing that motion studies were more scientific than Taylor's time studies. Taylorists spoke of increasing effort, Gilbreth of reducing fatigue. Over time, however, those who styled themselves 'efficiency experts' came to apply both time and motion studies, as appropriate. Motion studies led to improvements in workplace organization, and the better understanding of fatigue, which have remained in place in industry to this day.

Personnel Management

Another variation of the work efficiency movement occurred in personnel management and involved the use of professional personnel managers to make hiring, firing, and promotion decisions within the firm. Even though Taylor was hostile to this change, his overriding message that planning and rational procedure would increase productivity paved the way for personnel management. In particular, personnel managers followed Taylor's system by trying to eliminate the all-powerful factory supervisor. However, unlike Taylor, they recognized that the scientific principles of the new management would not necessarily reduce workers' objection to authoritarianism or disguise the bosses' disdain of workers' opinions. They recognized that hiring from within by seniority, and offering other benefits, could build worker loyalty to the company. Also, in contrast to Taylor, personnel managers noted that it was more efficient to hire those with aptitudes for a job, rather than weeding out later those who performed poorly. Unlike both Taylor and Gilbreth, they did not think that firms should treat workers like machines.

Scientific management and the increased use of the assembly line acted to encourage the rise of personnel management by replacing skilled with unskilled workers. Skilled workers could readily move from building farm equipment to building cars because they would be familiar with the machines and could read blueprints. Unskilled workers would have to be trained in the details of any job. The high rates of labor turnover that had always characterized American industry thus became much more important in the early decades of the twentieth century. Employers calculated that training costs could be many times higher for the unskilled; they were then receptive to personnel managers who promised to lower turnover.

Personnel departments date from about 1885, but only after 1910 did many firms join the movement. World War I and, especially, the Great Depression were periods in which both business leaders and government were extremely anxious to placate union leaders. Personnel managers claimed that they could make both firm and worker better off by instituting centralized hiring, promotion by seniority, and safeguards against arbitrary firing. They insisted that by using psychological tests, they could choose and assign workers much better than their supervisors. They also claimed that psychological incentives (eventually including company sponsorship of canteens, and sports and cultural activities)—not just wages—would increase productivity and company loyalty.

Personnel management sometimes went well beyond these measures. Ford, for example, installed a Sociological Department whose members visited workers' homes and gave their families advice on nutrition and cleanliness. Ford's investigators also lowered the pay of, and eventually removed, those who did not maintain an appropriate moral lifestyle.

The personnel techniques advocated by Elton Mayo were subtler. This Australian-born social scientist found in 1927 that workers at Western Electric responded with higher productivity simply to the interest shown by investigators measuring the impact of a new lighting system. Workers in a control group whose lighting had not improved nevertheless increased their output. Based on these and other experiments at Western Electric's Hawthorne plant, Mayo concluded that positive interaction between worker and manager could raise productivity without any improvements in machinery or incentive systems. Mayo gained much fame for his 'Hawthorne effect.' Among the practical means of improving the psychological environment of the workplace, attractive lunchrooms were a common innovation, as were 'suggestion boxes' and workgroup discussions for improving efficiency. Workers would work harder if they believed that their firm cared about them. The new science of industrial psychology (followed by industrial relations) was thus born. Even proponents of scientific management incorporated psychological ideas in their work after that.

The Assembly Line

The assembly line drew inspiration from the broad movement of scientific management. However, it would have a much more significant impact than did Taylor, Gilbreth, or Mayo. It would dramatically change the nature of industrial work.

One essential precondition for the assembly line was interchangeable parts. Only if parts were highly standardized could either a worker or a machine attach part A to part B like clockwork throughout the working day. As we saw in Chapter 6, the key to interchangeable parts was the use of highly specialized machinery designed to manufacture particular components. As their scale of production increased, automakers had turned increasingly to the use of such specialized machinery. As early as 1908, Cadillac had demonstrated that its cars could be disassembled, the parts mixed up, and the vehicles easily reassembled.

Another prerequisite of the assembly line was production in series. Entrepreneurs before and after factory mechanization moved unfinished goods from one specialist to another. Oliver Evans developed an automatic flourmill in the 1790s. In the nineteenth century, James Bogardine, recognizing that the use of iron in construction allowed greater freedom in factory design, recommended that machines be situated to enhance the flow of intermediate products. Still, through most of the nineteenth century, intermediate goods had to be carried from one workstation to the next, and these were often in no particular order. Some car manufacturers had begun around 1900 to move the car chassis from one station to another on wheeled platforms.

The railroad allowed meatpackers to serve a national market, first in salted pork, and then, after the development of the refrigerated rail car, in beef as well.[1] Meatpackers responded with the division of labor, and by seeking outlets for animal parts that were uneconomical to process in small-scale butcher shops. They were thus able to outcompete local butchers, and soon overcame public skepticism of frozen meat. From the 1860s, the meatpacking industry introduced overhead trolleys from which carcasses were suspended and manually pushed past meat cutters. Later these trollies were powered. Not only did these 'disassembly lines' eliminate the work of manhandling huge slabs of meat, but—as Taylor himself could appreciate—the speed of the conveyor regulated the pace of work and made it impossible for the worker to shirk (or, notably, to be paid piece rates). Canning, flour milling, and brewing were other industries that made early use of conveyor belts.

One last antecedent of the assembly line was the work of Taylor and Gilbreth themselves. To put together an elaborate machine such as an automobile on a conveyor belt, one had to have precise knowledge of the time and space required for the performance of each task. Both time and motion studies were used to determine the best speed for the conveyor belt, the best heights of workstations, and the appropriate placement of workers and machines. The assembly line itself then served to both discipline individual workers and coordinate diverse workers better than Taylor or Gilbreth could achieve. Moreover, the assembly line changed the jobs workers performed whereas Taylor and Gilbreth sought to improve the performance of existing jobs.

Henry Ford hoped that if he produced automobiles on a mass scale, he could reduce their price to a level that the broad middle class could afford. Having grown up on a farm, Ford was particularly aware of the vast market for cheap and reliable transport among the dispersed agricultural population. At first, he was confident that specialized labor and improved machinery alone would be sufficient to produce a mass-market car. As he lowered his prices and expanded his output, his engineers needed to develop improved methods of production. It may thus be critical for the development of the assembly line that the automobile industry was relatively new and had much room to grow. Ford's engineers began experimenting with a small assembly line for building flywheel magnetos (which powered the electrical system); they found that assembly time fell from twenty minutes to five minutes. They engaged in further experiments with other components. In 1913, Ford's staff then established a much larger line for assembling the car chassis itself. With the use of a rope to pull the chassis past components, assembly time fell from over 17 hours to just six; by powering the movement of the chassis and by designing specialized workstations, the time declined to one-and-a-half hours by late 1914. Though Ford seems to have been skeptical at first, this bold step allowed Ford to achieve his dream of a mass-market automobile (see Chapter 15). Many industries soon modeled their factories on the Ford assembly line.

Ford's Highland Park factory had not been designed for the assembly line. It had been built for electrification. It was a large, well-lighted space, with electric wiring throughout. Ford was thus able to experiment with new types of work organization. Electrification had the further advantage of allowing workers to work in shifts well into the evening, thus allowing increased use of the specialized machinery associated with the assembly line. Moreover, electrification encouraged the use of interchangeable parts: It was challenging to maintain consistency in machine speed over time or across machines when these were connected to an external engine by a system of belts. Machines closer to the engine often moved faster and speeds changed if a machine was disconnected for repair.

The Ford assembly line required that each worker perform only one repetitive and straightforward task (thus allowing unskilled workers to master the job quickly). It also encouraged the development of specialized machines for each workstation (often aided by motion studies). Within decades, the word 'automation' would be coined to signify (part of) an assembly line that could function with virtually no human involvement. Less obviously, the assembly line eliminated the many workers previously required to bring parts to assemblers. The Model T had some 10,000 parts, and there was thus a considerable advantage to collecting each precisely where needed in the production process rather than distributing them to cars being built in different places.

To lower costs, Ford originally decreed that all customers would get the same car. The development of the assembly line depended on this vision of millions of identical automobiles. He was soon forced to recognize that the marketplace wanted variety. As assembly line technology evolved, it became possible to accommodate a diverse market; the same line could produce automobiles with a variety of different options. Of course, if tastes change, and products are redesigned, much expensive specialized machinery may become obsolete. Auto manufacturers then had a powerful incentive to make only minor model changes from year to year. Only in recent decades have numerically controlled machine tools (as previously described) provided the flexibility required to respond quickly to changing and diverse markets.

Even though the assembly line has dramatically improved our lives as consumers, it has not been without its costs. In particular, it has removed the last vestige of artisanship from industrial production and placed millions of workers in the position of having to perform repeatedly the same mindless tasks all day. Machines regulate the workday more than Taylor with his stopwatch could ever have hoped to do. Automation would eliminate many of the most repetitive and onerous jobs, and in recent years American firms have begun to copy European and Japanese manufacturers by circulating workers among positions. Still, the assembly line and scientific management threatened cherished values of workers.

Hardly anyone used the phrase 'assembly line' until the 1920s, but it was soon appreciated that this was an important production technology that could dramatically lower costs of production. Assembly lines were employed to produce various goods, including foods, appliances (fridges, toasters, washing machines, irons, fans), tires, equipment, toys, tools, bicycles, and games (Figure 13.3). Still, it was not the only pivotal process innovation of its time. In industries producing a homogenous output, whether paint, ketchup, or gasoline, continuous processing, in which inputs moved continuously through a series of mixtures or chemical transformations, would play a role analogous to that of the assembly line. Many industries—furniture, jewelry, cutlery—could not adequately adopt mass production techniques of either type, for they had to produce small quantities of goods for different users; the machine tool industry discussed previously would rely on batch production of specialized

Figure 13.3 Milk bottling assembly line, likely 1920s.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

mass-production machinery until well into the age of numerical control. Many firms adopted only some aspects of assembly line production: Machines were commonly placed in the order of production, and conveyor belts were also widely used to move products between stations.

Labor's Response

Scientific management seemed to undermine especially the traditions of skilled workers. A famous case is the strike of metalworkers at the government-owned Watertown Arsenal in 1911. This prompted a Congressional investigation, the results of which give us considerable insight into how workers felt about Taylorism. Workers did not like being watched and analyzed while they worked. They still clung to the independence of the artisan and objected to being treated like machines. The Watertown strike had begun when a molder refused to be timed, walked off the job, and was joined by all of his workmates. Taylorism was banned from government sites for three decades.

Workers knew that time (and motion) studies implied changes in wages and supervision. While Taylor emphasized the fact that total wages would rise, it was nevertheless true that piece rates themselves usually fell; workers who could not accelerate their work enough to compensate would suffer even if they did not lose their job. Taylor could not prevent employers from reducing piece rates so much that workers merely ended up working much harder for the same pay; his system looked to workers like just a fancy name for the age-old practice of speeding up work. Taylor's reforms led to a multiplication of supervisory personnel—'white shirts,' separated by education and experience from those they supervised. Workers resisted these often-young supervisors, who had little 'real experience' in the workshop.

Taylor's reforms struck at the heart of union solidarity. Unions had always fought for a standard wage, to prevent discrimination by supervisors and to encourage collective consciousness. Taylor wanted to accentuate the differences in worker incomes to promote an expanded work effort—and thus wanted to set wages scientifically rather than through collective bargaining. Some workers excelled under these incentives and might even have been promoted into the new supervisory positions, while others fell by the wayside.

The union leadership correctly saw Taylorism as a threat to their authority and were able to impede the use of stopwatches in some cases. They were, however, less successful against a gradual adoption of scientific management principles, especially where new production technology eroded old work practices and gradually replaced skilled workers.

Progressive-era reformers, such as Louis Brandeis and Josephine Goldmark, were sympathetic to workers' concerns about long hours and fatigue. Nevertheless, they and many members of the public were also in favor of increased efficiency. When, for example, eastern railroads lobbied the government for higher freight rates in 1911, complaining that rising labor costs were to blame, efficiency experts claimed that the railroads could save a million dollars a day with scientific management. The public largely embraced this idea; while sympathetic to the workers' dislike of being treated like machines, they were more sympathetic to the experts' claim that increased efficiency could markedly improve everyone's standard of living.

Even labor leaders gradually developed a more positive attitude toward scientific management. Workers had long resented incompetent supervisors wasting their time by failing to deliver needed work materials. They could thus appreciate attempts to coordinate production centrally. More subtly, Taylor's methods might in fact raise wages, lower consumer prices, and even reduce working hours. In response to the Watertown strike, Taylor insisted that his system would usher in a 'mental revolution' by ending class conflict in the factory. Scientific management would increase "the size of the surplus until the surplus became so large that it was unnecessary to quarrel over how it should be divided."[2] During World War I, trade union leaders joined managers on war production boards and were in part won over to the gospel of efficiency. Taylor's mental revolution became the basic rationale for the eight-hour day, which was adopted in Western Europe and in many American industries in 1919. Gradually, unions accepted efficiency measures as a trade-off for higher wages. In the 1910s and 1920s, advocates of scientific management, such as Morris Cooke, came to view unions as potential partners in reorganizing the workplace. Unions, if they could allay workers' fear that they would *not* in the long run benefit from improved productivity, could elicit from workers themselves suggestions as to how work might be better organized. Firm managers, however, were much less willing than the experts to forge cooperative links with the unions.

The frustration that workers felt toward Ford's assembly line also declined over time. Like other employers of large masses of increasingly unskilled labor, Ford had difficulty keeping a stable workforce. Autoworkers did not organize and strike; instead, they expressed their discomfort with the increased pace and boredom of factory work by high rates of absenteeism and hopping from job to job. Ford had to replace his Highland Park workforce almost four times in 1913. In response to this threat, which was bound only to grow with the coming of the assembly line, in 1914 Ford introduced the five-dollar day. This represented nearly a doubling of the average wage for unskilled labor in American factories at the time. Ford also hired immigrants and blacks with limited employment opportunities, and also thousands with physical or mental disabilities. Ford's turnover problems declined. Indeed, like Taylor, Ford gained a reputation in Europe as well as the United States as an advocate of a 'high-wage' economy. The five-dollar day, however, had a hitch. Only workers who passed muster with Ford's paternalistic Sociological Department would earn it. Workers had to have stable family lives and no drinking problems, for example. Ford soon disbanded the Sociological Department, and by the 1920s workers' wages at Ford were no higher than the wages of other autoworkers. Ford's promise of high wages in exchange for accepting tedious, repetitive factory work expressed a now common understanding of industrial work as a means rather than an end.

The basic ideas of organizing work centrally, simplifying tasks, wage incentives, and assembly lines became standard industrial practice. Penn State in 1908 recognized industrial engineering (which involves the designing of production processes, including layout, training, and scheduling, and the devising of management systems) as a university program. It is now a staple element of engineering programs.

Workers and unions, willingly or not, accepted the trade-off between higher wages and reduced independence that both Taylorism and the assembly line represented. And in the 1980s and 1990s, business leaders began to advocate increased input of workers into the organization of production—an idea promoted by personnel managers and union leaders for most of the twentieth century. Ironically, the stopwatch made a comeback in the 1990s at the GM-Toyota plant in Fremont, California, but this time in the hands of work teams trying to increase productivity.

Notes

1 The meatpacker Gustavus Swift funded the development of the refrigerated rail car in 1881. Railroads opposed the technology, for they made more money shipping live cattle. The Canadian Grand Trunk Railway had limited live-cattle traffic due to its longer route from Chicago to the East Coast, and thus accepted refrigeration; other railroads followed. Refrigeration would soon provide national markets for a range of goods, notably beer.

2 Frederick W. Taylor, *The Principles of Scientific Management* (New York: Norton, 1967), 19–24, and "Testimony Before the Special House Committee," in *Scientific Management* (New York, 1947), 24–30.

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14 Innovation and the Great Depression, 1918–1940

The fluctuations in American economic activity in the twentieth century raise the following question: Is there any connection between innovation and economic activity? During the Depression of the 1930s, many people believed that labor-saving innovations were responsible for a large part of the unemployment problem and that new products were introduced too slowly to absorb these displaced workers. We must look at the issue more broadly, however, by asking when and why innovation occurred in both the booming 1920s and the depression years of the 1930s, and what impact it had on the economy.

Innovation Clusters and Economic Fluctuations

Since the time of the First Industrial Revolution, technological innovation has been the primary engine of economic growth. As we have seen, however, such innovation does not occur evenly over time. A cluster of innovations, for example, precipitated The Second Industrial Revolution (Chapter 9). The preceding decades had seen sluggish economic performance, as the technological potential of the First Industrial Revolution had largely been achieved.

Some innovations increase employment while others do not. The development of new products usually encourages both investment and employment. New labor-saving methods for making existing products, however, tend to decrease total employment. Of course, new products that replace existing products reduce jobs if the new technology employs fewer workers than the old (as was the case with the rayon industry). Even more critically, labor-saving technology leads to more jobs if sales expand more than productivity (as was the case with the assembly line in the automobile industry). Still, we might expect higher unemployment during a period in which labor-saving technology was abundant and there was a lack of new products.

This is not to say that labor-saving technology is harmful; after all, it has produced modern affluence. Workers have long viewed such technology with apprehension, for it has often meant that those with particular skills have lost their jobs. In the long run, however, new jobs have been created to replace the old. Unemployment rates were no higher in the twentieth century than in the nineteenth, due to the development of new products on which to spend our money.

From our perspective today, this may be comforting. To many Americans living during the Depression, however, 'technological unemployment' seemed very real. It is arguable that this unprecedented slump was due in large part to the introduction of much labor-saving technology without a similar growth in new product innovations. Another factor to consider is the tendency for sales of consumer durables (e.g. cars) to be erratic: Stagnant sales may follow the rush to purchase new products because such durables may last for many years. This phenomenon was quite evident in the 1920s and '30s, a period when consumer durables were beginning to play a decisive economic role. The bunching of durables expenditures was encouraged by developments in advertising (due to radio, and advances in printing techniques) and installment credit in the 1920s.

The Great Depression of the 1930s

The thesis that the timing of technological innovation explains the Great Depression is controversial. Economic historians remain divided as to the causes of the Depression. One school of thought has attributed the Depression mainly to miscues made by the Federal Reserve Board, which restricted the money supply and weakened the banking system. An alternative explanation is that sharp declines in investment or consumption depressed output and employment. Neither theory has satisfied most economists: They usually consider the first too weak to explain the entire calamity, and the second does not tell why these declines occurred in the first place or were so slow to be reversed. A shortage of new product technology, aided by a large quantity of labor-saving process technology, could provide a third and more satisfying explanation. Moreover, such an explanation could complement the other two.

The 1920s witnessed the widespread adoption of three major process technologies—the assembly line, continuous processing, and electrification. By the end of the 1920s, most firms that were going to adopt one or more of these technologies had undertaken the necessary investment. Labor productivity continued to rise in the 1930s but required little investment: Organizational changes improved the performance of existing technologies, and new tungsten carbide cutting devices were easily affixed to existing machines. At the same time, the decade between 1925 and 1934 was the worst in the last century and a half regarding the introduction of new products. An exception was the electric refrigerator; sales of these expanded through the 1930s. This suggests that if there had been many other new products, they would have substantially alleviated the unemployment problem.

Why should the interwar period have been characterized by a surfeit of process technology and lack of new product innovation? The technological breakthroughs of the Second Industrial Revolution in electricity, chemicals, and internal combustion each yielded major new products well before 1925 and well after 1934, but almost none in between. Automobiles, radio, and rayon hit the market well before the Depression, whereas commercial airplanes, television, and nylon, for example, had their primary impact after World War II. In each of the cases cited, the later innovations required a much higher degree of technical sophistication than the earlier; this helps explain the long temporal gap between them.

Each of the three pivotal innovations of the Second Industrial Revolution also spawned labor-saving process technologies during the 1910s and 1920s. The automobile introduced the assembly line, and this idea was adopted widely by other industries in the 1920s. Its counterpart in the chemical industry, continuous processing (in which materials were moved steadily through the production process rather than being transformed in batches), was pioneered in the last decades of the nineteenth century. Industries as diverse as paper, oil, and food processing adopted it in the interwar period. Even more revolutionary was the widespread application of electricity to industrial machinery: The decade of most rapid electrification was again the 1920s.

We should note that radio manufacturers did not pursue research into television as quickly as they might have (see Chapter 17). Technical considerations were not the only determinant of the timing of innovation. The industrial research lab likely tilted the efforts of researchers away from product and toward process innovation. The earliest labs were set up to protect market position in *existing* product lines—Kodak's cameras, GE's lightbulbs. Thus, they naturally focused on improving the process for producing these goods. Over the course of the next decades, a handful of significant product innovations in research labs, such as vacuum tubes, encouraged lab managers to pursue more far-reaching goals. Still, research labs appear to have been conservative in their attitude toward developing new products in the interwar years. By focusing on process innovation, they exacerbated the imbalance between process and product innovation, replacing workers who had nowhere to go.

Of course, technology cannot explain all economic trends in the interwar years. Falling birth rates reduced population growth, as did stricter immigration laws. This trend meant less investment in anticipation of growing markets. Moreover, disparities in household income increased during the 1920s, reducing the income of those most likely to spend. Nevertheless, there remains a good case for the impact of technology.

Product Innovation in the Interwar Period

The new products of the early 1920s were primarily consumer durables. These often saturated their markets within a few years, and thus sales and employment fell at the time of the Depression. The most important by far was the automobile, which became an item of mass consumption in the early 1920s. By 1929, more than one American in five owned a car. By the mid-1920s, automakers had already begun to worry about market saturation. Since individual firms were fighting each other for market share, however, they could not hold back on production. GM introduced yearly style changes in an attempt to stimulate trade-ins, but this was not enough to overcome the saturation of the first-time buyer's market. There were few significant product improvements during the latter 1920s or 1930s. On average, people kept their cars for seven years. In 1929, 75 percent of vehicles had been purchased within the last five years. A decline in output was inevitable. Auto sales and production started to fall in March 1929, several months before the economy as a whole began to decline.

The first simple household appliances, such as irons, had emerged in the early 1900s, and 81 percent of wired households possessed one by the late 1920s. Half of urban American homes were wired by the early 1920s. Waffle irons, hot plates, heaters, toasters, and clocks were other early electric appliances. The more complex washing machines and vacuum cleaners had come along in the 1920s, but the affluent first-time market for these products was saturated by 1929. More impoverished Americans, of course, still could not afford such luxuries. Some scholars have suggested that appliance sales would have been much higher if electric utilities had extended service and lowered rates, as they would under New Deal encouragement in the 1930s (the government-sponsored Tennessee Valley Authority showed that the poor would use electricity if it were inexpensive). Appliances sales did vary depending on how aggressively local utilities marketed them to consumers.

The 1920s witnessed the emergence of industrial design as a profession. Appliance and furniture manufacturers, like automakers, hoped that changes in design could enhance sales. In the 1930s, many commentators hoped that redesign of products would stimulate consumption and thus employment. Designers were influenced by European modernism, which celebrated the machine and increasingly favored a sleek aerodynamic look. Not surprisingly, designers drew heavily on new plastics, enamels, and alloy steels, and downplayed wood. It does not seem that they had a dramatic effect on overall sales volumes in the 1930s.

Not all durable-goods producers experienced market saturation on the eve of the Depression. The demand for the radio, appearing first as a household appliance in 1922, grew slowly but steadily in the interwar years, because radio adoption followed electrification. The country home remained mostly without radios until the mass rural electrification projects of the 1930s, although many farmers used battery-powered radios in the 1920s. Moreover, improvements in size, appearance, and quality of radio apparatuses encouraged a healthier repurchase market. Nevertheless, drastic reductions in the cost of radio production over the course of the 1920s and 1930s ensured that both the value of output and employment fell steadily from 1929.

The rayon industry, whose output grew before World War I and then exploded in the 1920s, served mainly to provide substitutes for products that were more labor-intensive in production (such as cotton, wool, or silk textiles).

Indeed, research efforts throughout the chemical industry in the first decades of the century were devoted to lowering the costs of producing chemicals similar or identical to those already in use.

There were very few new product technologies that appeared in the critical years of the late 1920s/early 1930s. One was the electric refrigerator. Sales of this consumer durable did expand steadily through the early 1930s, despite the Depression. This one industry could hardly have created enough jobs to offset the depression in other sectors (Figure 14.1). Talking motion pictures (1927) were another new product (see Chapter 16). This technology provides an important illustration of the fact that product innovation need not enhance employment. Increased demand for projectionists roughly balanced the decreased demand for theater musicians to accompany silent films. The numbers assembled in Hollywood to produce the movies in no way replaced those who had previously provided entertainment in a more decentralized fashion in vaudeville houses across the nation (radio also contributed to the death of vaudeville).

Whereas product saturation occurred in cars and some household appliances in the late 1920s, other 'children' of the Second Industrial Revolution entered the market too late to have an economic impact on the Depression. Airplanes had been used during World War I, of course, yet only halting steps toward commercial aviation were made during the 1920s. The DC-3 airplane of 1935–1936 ushered in a new era in commercial aviation. Costs per passenger

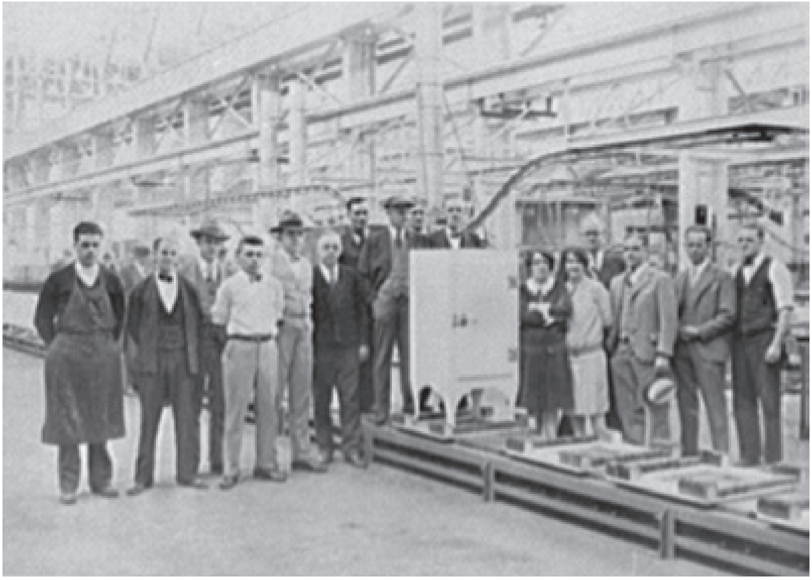

Figure 14.1 The first electric refrigerator rolls off the assembly line, 1928.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

per mile flown were only one-quarter of the level possible in 1929. As well, improvements in airport facilities and traffic control over many years further enhanced the viability of commercial aviation. After World War II, airplane production and operation became one of the fastest growing sectors.

The diesel locomotive, like the airplane, was more complicated than the automobile. It might well have been developed before 1930 if the locomotive industry had embraced the idea. Three firms, two of which were among the seventy largest industrial firms in the country in 1917, had long dominated steam locomotive manufacture in the United States. Although these firms had the financial resources to develop diesel technology, they lacked familiarity with internal combustion and proved hesitant to adopt the mass production that diesel engines allowed and encouraged. General Motors would spend some $20 million on research in the early 1930s, after buying patents from others, and marketed diesel locomotives from 1934. Railroads would invest heavily in diesel locomotives—steam had largely disappeared by 1959—as these required much less labor to operate and maintain and had three times the energy efficiency of steam locomotives.

Like commercial aircraft, television came too late to invigorate the economy in the 1930s. Although experiments with mechanical-scanning TV occurred in the late 1920s, picture quality was exceedingly weak. Success in electronic scanning happened only at the very end of the 1930s. War and regulatory delay ensured that commercial television in the United States would prove a postwar innovation. Similarly, in the 1930s, many new chemical-based industries were born. Significant product innovations in the fields of plastics, nylon, synthetic rubber, pharmaceuticals, and food additives would enter the mass market, but only after World War II.

The economic sectors that created the most significant growth in employment and output after 1945 almost all relied on technology not available in 1929. The list includes television, commercial aircraft, nylon, various other synthetic fibers and plastics, various new drugs, and eventually a host of new chemicals or electronic products. The government also expanded, especially the military whose expansion depended on both political considerations and new technology. We discussed above various technologies developed during the late 1930s; in addition, there was research during World War II in areas as diverse as jet aircraft, radar, and pharmaceuticals that would have significant economic impacts after the war. To be sure there were other factors at work, including revitalized auto and residential construction sectors, which naturally bounced back from more than a decade of low levels of activity (housing construction had boomed and declined in the 1920s, due primarily to an auto-induced migration to the suburbs). The baby boom—itself a response both to economic prosperity and to low birth rates during Depression and War—likely encouraged consumer spending, and governments actively sought to encourage employment and economic growth. Nevertheless, we should not ignore the impact of myriad innovations of the late 1930s or early 1940s.

Labor-Saving Process Innovation in the Interwar Period

Although technology introduced few new consumer goods in the interwar years, innovators produced a host of new processes that tended to eliminate jobs. A new generation of machine tools appeared in the early 1920s. These new machine tools increased product quality while reducing the need for workers. The center of machine innovation was the growing auto industry. Carmakers needed accurate tooling but had no significant investments in old machinery to worry about. Once perfected for the auto industry, these machine tools spread through industry in the 1920s.

Electricity was soon applied to these new machine tools. While only 4 percent of powered machinery was electric in 1899, and only 30 percent in 1914, 75 percent was in 1929. During the 1920s, horsepower per industrial worker in the United States rose 50 percent. Trucks equipped with electric batteries, for example, replaced three workers on average in materials handling; at least 36,000 jobs disappeared over the course of the decade due to this innovation alone.

The electrification of the factory had multiple effects on production. Previously, about one-quarter of the power generated in a factory was lost in the system of gears and belts that connected an engine to various machines. Further efficiencies arose as electrical utilities powered factories rather than each factory building its own engine. As recognized in the preceding chapter, electrification allowed machines to be placed where they were best suited to the production process and run at the ideal speed; previously location had depended on connections to an engine and speed varied with location and the number of machines being powered. In addition to the general benefits, there were a host of industry-specific improvements. Electric thermostats allowed bakers to achieve precise outcomes with mass production techniques. Electric furnaces were much hotter than coal-fired furnaces, facilitating continuous processing of molten metals. Electric lighting aided shift work not just in factories but also in warehouses and stores.

The assembly line dominated auto production in the 1920s, and was used by the new consumer durables from the outset; a host of older industries, such as the manufacture of cans for canning, adopted the technology in the 1920s. Analogous to the assembly line, but less well known, was continuous processing: A series of operations (usually chemical reactions) produces a uniform product such as gasoline, steel, paper, or mustard. Chemical engineers from Du Pont and other large firms devoted much research to reducing the cost and increasing the quality of their output. Over time, various apparatuses were developed to achieve automatic control of temperature, pressure, humidity, specific gravity, and weight and volume of flow. Oil refining provides perhaps the most dramatic example of the interwar application of continuous processing; beyond a direct labor saving over batch methods, continuous processing was able to almost double gasoline yields over batch methods by the end of the decade.

We should stress again that the assembly line, electrification, and continuous processing were among the major process innovations of the modern era. It is noteworthy that all three were adopted widely during the interwar period. All three can be traced to the Second Industrial Revolution: The internal combustion automobile inspired the assembly line, the commercialization of electric power encouraged electrification of industry, and the production of a range of chemicals encouraged continuous processing. These process innovations have each allowed the American economy to supply a variety of products at much lower cost than before. However, the simultaneous introduction of all three technologies disrupted the labor market at the time.

Other technological and organizational changes increased productivity. Tractors, excavating machines, and paint sprayers raised output per worker in farming and construction. New business schools, and the psychological and sociological extensions of scientific management, transformed management techniques. Trade associations and government efforts at standardization encouraged the interfirm transmission of 'best practice' technique. Firms moved toward longer-term attachment to their labor force; this supported (and was supported by) greater efforts toward training.

We should also remember the industrial research laboratory. While some labs devoted some effort to developing new products, and others attempted to stimulate consumer interest by making minor improvements to products, it appears that most effort at this time was expended on process innovation: Trying to reduce the costs of producing existing goods. Firms thus developed new processes of particular importance to their products.

The cumulative result of all this was that labor productivity rose faster in the 1920s than it ever had before, and nearly as fast as it would rise during the glory decades of the postwar boom. Industrial output was thus able to increase 64 percent in the decade with virtually no change in employment. In agriculture, mechanization released over a million workers per year, but they had few places to go. Years before 1930, the American economy had millions of unemployed in the cities, and millions more disguised unemployed (workers who lacked jobs but did not appear in estimates of unemployment) in the countryside. Moreover, many firms retained redundant workers during the 1920s but were forced to let them go in the 1930s.

Capital productivity—the output per dollar invested—expanded faster in the 1920s than it ever has before or since. The new technology saved even more capital than it did labor. Among other things, this reduced the amount of investment necessary in the 1920s to take advantage of the new technology. By the end of the 1920s, the required investment to take advantage of new process technologies was mostly in place. With market saturation in old industries, and little new product development, there was thus little scope for investment to compensate for flagging consumption expenditure and thus create jobs in the 1930s.

Despite massive unemployment, process innovation continued through the 1930s. Output per worker-hour in manufacturing rose another 25 percent. Although national output was higher in 1939 than 1929, total employment was about 3 million less. Not surprisingly, many voices inside and outside government came to advocate measures to limit the pace of mechanization.

Automobiles and the Great Depression

In the next chapter, we will discuss the development of the American automobile industry. We noted above that automobile production had expanded dramatically during the 1920s, and the market for automobiles had become saturated by 1929. General Motors had begun to experiment with annual model changes, but most car owners saw little need to purchase a new vehicle. The automobile industry was thus an important component of the economic prosperity of the 1920s and arguably a key contributor to economic decline after 1929.

We should stress in this regard that sales of automobiles began to decline early in 1929. This decline thus occurred long before the Stock Market crash of October 1929, which is seen by many to signal the onset of the Great Depression (though we have seen in the late twentieth and early twenty-first centuries that dramatic downturns in the Stock Market need not trigger economic downturns). Since the automobile sector had become a significant consumer of iron, glass, and rubber, among other inputs, a slowdown in automobile production had severe implications for American industry as a whole. Indeed, automobiles had come to absorb fully one-eighth of the value of American industrial output by 1929. The fact that the vast majority of Americans who could afford a car already had a relatively new one in 1929 thus ensured a significant decline in industrial production. This would inevitably result in workers losing their jobs not just in automobile production but in the many sectors that provided inputs to automobile production.

The development of automobiles also had important effects on labor productivity that further exacerbated the interwar employment problem. The introduction of mass-market automobiles encouraged the construction of paved roads both within and between cities. Improvements in roads, in turn, led to productivity advances in transport and wholesale and retail trade. In particular, trucking firms expanded to take advantage of the newly paved roads and developed better synchronization with railroads. Costs of moving both raw materials and finished goods thus fell. The development of superior tires for trucks allowed them to carry more and travel faster on the new road system. The number of workers required in the transport sector, and in warehousing and retailing, was thus much lower than it would otherwise have been.

The Technocracy Movement

At the outset of the twentieth century, technology was widely hailed as unambiguously good. The war tarnished this view considerably (much less in the United States than in Europe), but it was the widespread unemployment of the interwar period that caused many to question the benevolence of technological advances. Observers coined the term 'technological unemployment' in the 1920s to describe workers who lost their jobs to machines. They recognized that the phenomenon was not new, but concern about the effect of machines on jobs naturally rose during the Depression.

One result of the Great Depression was the rise of the technocracy movement. In contrast to those who advocated a slower pace of innovation, the technocrats, along with the bulk of the American populace, continued to believe in the benevolent effects of technological change. They thought that institutions should be changed to reflect technological trends, rather than the reverse.

Technocrats did not agree on the exact form of these new institutions. Inevitably influenced by events in the former Soviet Union—the 1930s was perhaps the only decade in which the Soviet economy grew faster than that of the West, and unemployment seemed nonexistent there—technocrats advocated a managed economy. They recognized that technological unemployment could be eradicated by merely increasing production; if the market would not do this, some other mechanism had to be found. They were confident that this could be accomplished within a democratic framework, although they wanted a government that would make decisions solely on technical grounds.

One significant influence on technocracy was scientific management. Taylor had argued that factories could be organized scientifically. Technocrats believed that the entire economy should be arranged similarly. This was a popular idea. Presidents Hoover and Roosevelt had both pursued the ideal of allowing experts freed from political interference to coordinate economic activity. Hoover favored cooperation with the private sector, while Roosevelt was more willing to issue directives. Technocrats placed great faith in the ability of experts to manage society efficiently. If experts could so radically improve our technology, why not society itself? But technocrats never precisely explained how this could occur, and the movement soon lost followers. Nevertheless, the question of how society should adapt to (or attempt to control) ever-changing technology remained a vexing one.

Could It Happen Again?

There are concerns in the early twenty-first century that developments in artificial intelligence may lead to the replacement of many middle management jobs. Computers, that is, may be able to perform a variety of functions that are at present performed by humans. If we accept that technology played a role in the Great Depression, then we might worry that another major process innovation might again yield massive unemployment. We can take some solace in the fact that the economy has become much more diversified than it was in 1929. There is no sector like the automobile sector of 1929 that could yield massive unemployment on its own. There is also less likelihood of an economy-wide lack of product innovation. Recall that process innovation is only problematic if displaced workers have no place to go. We will discuss in later chapters the possibilities of new product innovations in diverse areas such as biotechnology, nanotechnology, electronics, and artificial intelligence itself. We might also note that governments reacted quite differently to the Great Recession of the twenty-first century than they had to the Great Depression of the 1930s. Though economists debate the importance of government policies in both time periods, we can be confident that governments will not feel helpless in the face of massive unemployment as they did in the 1930s. Moreover, government spending comprises a much larger share of the economy now than then, limiting the scope for sudden declines in employment. Governments may also replace workers with computers but may do so more gradually than the private sector. Last but not least, a host of social programs such as social security were put in place during either the 1930s or the early days of postwar prosperity (while the suffering of the Depression era was still in public memory).These will serve to protect those who lose their jobs from immediately plunging into poverty—and thus retain their ability to consume goods and services produced by others.

Still, an appreciation of the technological roots of the Great Depression might have policy implications. Most obviously, governments in their technology policies might try to encourage a balance between product and process innovation—though we should recall that it is not always easy to predict the effects of a particular innovation. Governments might also pay more attention to policies that retrain workers for jobs that cannot yet be performed by machines.

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15 The Automobile and Its Culture

The automobile was the product of the Second Industrialization that most transformed everyday life. It revolutionized transportation, eventually freeing most Americans from reliance on foot and hoof, and from the bother of consulting timetables and sharing space with others on trains and trams. The car put the individual in charge of when and where to go, doing so at amazing speeds. But the automobile became far more: It became a machine of great complexity where thousands of regulated explosions of gasoline and air drove pistons, crankshaft, transmission, differential, and wheels. To this were added a vast array of essential and optional gadgets: Brakes, radiators, alternators, carburetors, fuel and water pumps, and later heaters, radios, power windows and seats, and today even safety radar and sensors. The automobile might have remained a hand-crafted toy of the rich; instead, it was made available to the masses by advanced manufacturing techniques, especially the assembly line. With its thousands of parts to be put together, many of which had to move in tight-fitting spaces, specialized machinery and new organizations of work were required. The car stood at the top of a list of new consumer goods that entered the market around the beginning of the twentieth century. The automobile not only became an article of status and ever-changing fashion as well as utility, but it transformed the way that people shopped, housed themselves, and vacationed. It even became a marker of coming of age for millions of youth. The automobile became a necessity, but it also burdened its users with great expense, subjected them to new dangers and even death by collision, and contributed to the depletion of resources and the environment by vastly accelerating a trend that began with steam—the rapid consumption of fossil fuels, built by millions of years of life on earth.

Mass Production of Automobiles in the Land of Plenty

It began in 1885 when the German Gottlieb Daimler invented the first high-speed internal combustion engine (ICE). This machine required gasoline fuel for rapid vaporization replacing Gottfried Otto's earlier four-stroke engine (consisting of fuel intake in a cylinder, compression, combustion forcing down a piston, and exhaustion). Daimler introduced the carburetor, which both vaporized the fuel and mixed it with air for combustion. The downward push of the cylinder turned the crankshaft, passing rotary motion eventually to the wheels. Daimler's engine was much smaller and lighter than those that had gone before. This made it ideal for transportation. Shortly after Daimler produced his ICE, Carl Benz of Germany developed the first internal-combustion motorcar. It looked more like a motorized tricycle than the modern automobile.

Internal combustion's success depended on the solution of a number of tricky problems: Fuel and air had to be mixed correctly; the engine had to be cooled and oiled; a transmission had to be developed so that the vehicle would not stall at low speeds; a reliable starting mechanism had to be devised; additional cylinders had to be added to increase the power and speed of the engine, and suspension and tires needed improvement. These basic problems were not all solved until the first decade of the twentieth century. Moreover, as with electricity, the automobile could only truly succeed as part of a system of complementary technological and organizational innovations including oil and gasoline refining and road construction.

There were alternatives to the ICE: Both electric and steam-powered vehicles provided intense competition to internal combustion. In 1900, about 40 percent of motor vehicles were steam, 38 percent were electric, and only 22 percent were internal combustion. Stanley Steamers were produced in New England, offering power and familiarity to American consumers. Electric cars were simple to drive (no transmission or difficulties in starting). They were favored by urban drivers (especially women who presumably preferred the simplicity of the electric). However, the internal combustion engine proved superior in terms of both start-up time and range. The steam car required a ready supply of fresh water as well as fuel and it took about 20 minutes to get up a 'head of steam' to drive. Given the limitations of the batteries, electrics had ranges of only about 40 miles and top speed of 20 miles per hour, making highway driving nearly impossible. And charging time of six or more hours (if the driver could find an electric source) further made the electric impractical for Americans beyond large towns. Other factors sealed the deal for ICE in the 1910s: The discovery of large quantities of oil combined with cheaper gasoline made ICEs cheaper to run. The invention of the electric starter by Charles Kettering in 1912 eliminated the difficulties of the hand crank and the old advantage that the electric had in starting. With a growing network of gas stations, the ICE bested steam and electric with what consumers wanted—convenience, speed, range, and ease of driving.

J. Frank and Charles Duryea introduced the ICE automobile to the US in 1893. Quickly large numbers of car companies emerged (50 in 1902 mostly in New England). Production was limited by old methods: Parts manufacturing was decentralized and the lack of standardization made repair difficult. In any case, few manufacturers provided service. Most car companies simply assembled custom-ordered vehicles, often in cramped factories where parts were hauled to a stationary site where the vehicle was put together. All this guaranteed costly and low volume production.

Early cars were mostly playthings of the urban rich, modeled after the carriage of the affluent. Woodrow Wilson, the future president wrote in 1906, "nothing has spread socialistic feeling in this country more than the use of automobiles. To the countryman they are a picture of arrogance of wealth with all its independence and carelessness."[1] Car prices averaged $1,784 in 1905 when average annual wages were about $500. And this mean price included unreliable surrey-type cars (tiller-steered, motor-under-the-seat horseless carriages) as well as more luxurious models costing $4,000 or more. Wilson was right that farmers and small-town dwellers were upset when their horse and buggies encountered the new high-end, touring cars with a protruding front engines, steering wheels, and pneumatic tires that emerged after 1905. The car meant machine-driven speed, personal power, and mobility for the rich that contrasted with those still stuck in the ancient biological world of the horse and the newer, but annoyingly crowded and fixed routes of the railroad.

After 1905, however, Henry Ford sought to expand the market for cars, especially to reach the broad middle-class American (with high incomes when compared to Europeans). Ford's background on a Michigan farm near Detroit shaped his outlook: Though Ford had little education and many character flaws, including racial bigotry and a domineering personality that drove away many talented associates, he understood that farmers and small-town tradespeople were eager for a utilitarian vehicle. Later Ford manufactured sturdy tractors to replace the horse on the family farm.

That middle-class market had already been tapped by producers of low-quality, underpowered, and outdated vehicles (as, for example, a $200 car with a chain-driven, under-the–seat motor sold by Sears). But Ford introduced something different in 1908: The cheap, but modern and reliable Model T. It came with lightweight vanadium steel construction, a forward four-cylinder engine rated at 20 horse power, a drive shaft (rather than chain drive), a planetary two-speed transmission, pneumatic tires, flywheel magneto (for electricity), and acetylene head lamps. Still, the Model T was basic: No water, fuel, and oil pumps, and no gas gauge; and, its controls were tricky—a 'spark advance' lever for starting and accelerator lever both mounted on the steering wheel and three floor pedals, one for first and second gear, a second for reverse, and a third for braking. Yet it offered utility with its high-wheel base (good for rutted roads) and ease of repair (often by mechanically-skilled farmers and trades people). Moreover, its relatively low price of $950 in 1908 decreased progressively to as low as $290 in 1927. It is no surprise that it won the masses: In 1916, the Model T commanded half of the new car market, even with little advertising and financing. This dominance was accomplished by Ford's decision to limit model changes across the years of Model T production (1908–1927), including eventually restricting the exterior to black, keeping cost low.

He also built a closely-controlled and extensive network of dealerships that provided reliable service.

Most important to Ford's success was the assembly line that was installed in late 1913 at Ford's enormous Highland Park plant in Detroit. Instead of workers delivering parts to a stationary assembly station (where it took about 12 hours to construct a vehicle), the car from the frame to the completed vehicle moved along on an assembly line where stationary workers put on parts. This reduced assembly to 1½ hours. Individual parts moved along a belt or similar conveyor, obliging assemblers to keep up or lose their job. This led to very intense and often extremely monotonous work. The assembly line set the pace and method of work, often more effectively than did the time and motion studies of Frederick Taylor.

The assembly line transformed not only the arrangement of men and machines, but the composition of the workforce. While a typical metal goods factory in 1891 consisted of 40 percent skilled artisans, Ford's plant in 1917 had automated sufficiently to need only 14 percent skilled workers. With Ford's increased use of single-purpose machine tools and the introduction of the moving line, the proportion of machine operators increased from 29 percent to 55 percent while the proportion of parts carriers dropped from 29 to 15 percent. Interestingly, the percentage of managers rose from 2 to 14 between the 1891 factory and Ford in 1917. This reflected both the declining autonomy of once skilled workers and the complexity of arranging and controlling the accelerated pace of production.

While all this drove down the price of Model Ts, it also reduced the willingness of workers to take and keep jobs at Ford. Although American-born workers often avoided heavy factory work, this was even more so at Ford where 71 percent were immigrants in 1913, usually from southern and eastern Europe. Ford's management had to contend with extraordinary levels of annual turnover (379 percent). Conditions were harsh and many avoided or quit after a short time, especially because wages at Ford were comparable to other factories where the pace and controls were less.

Shortly after introducing the assembly line, Henry Ford found a solution by raising daily wages for line workers from $2.30 to $5 and reducing the workday to eight hours in an industry where the standard was ten. While this outraged fellow industrialists in Detroit, it solved Ford's problem with turnover and morale. However, there were strings attached: In order to earn five dollars, workers had to submit to investigations of their living arrangements: Workers who drank or abused their families or whose homes were dirty were refused the extra pay. Non-English speakers were expected to attend classes that taught not only English but preached middle-class morality and patriotism. While this intrusion was expensive and discontinued in 1921, it reflected Ford's hope of turning his workers into loyal Americans, devoted to family and aspiring to homeownership. With inflation, few wage raises, and Ford's turn to repressing union organizers, conditions in his factories became far less attractive.

But Ford gained the reputation for supporting high wages making it possible for his workers to buy the cars that they made and reduced workdays giving them time for family life and recreation (Figure 15.1).

Innovations in Related Sectors

The automobile could only succeed with the help of improved roads and service outlets. Early cars were mostly driven in and around cities where roads had been already built for sometimes heavy horse-drawn carriage and wagon traffic as well as bicycles. But auto enthusiasts (some of whom formed the American Automobile Association in 1902) encouraged improved and more extensive roadways. This led to many innovations: Power shovels replaced horses for road grading from 1910; two-thirds of grading work had been mechanized by 1925. Concrete mixers and finishing machines reduced labor needs by half.

After 1910, New York State led the way in providing paved highways. By the 1920s, there was a national network of highways, doubling in length in the 1920s and again in the 1930s. This system was created by the Federal Highway Act of 1921, which provided half the financing of US routes. American cities favored roads over public transit to a greater extent than European cities,

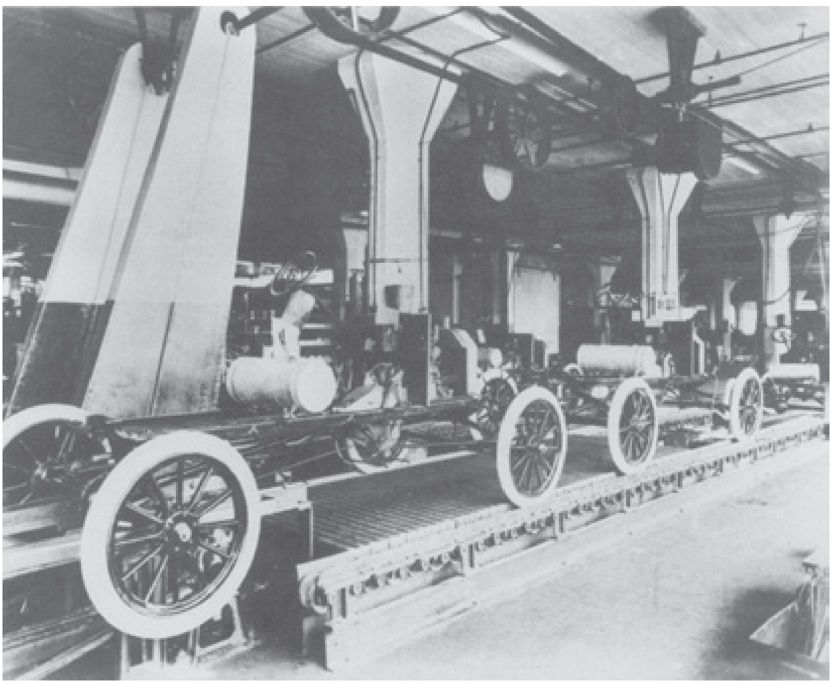

Figure 15.1 Ford Highland Park assembly line, 1913: The coil box on the dash of the model T was used to generate sparks.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

leading to both the neglect of rail transport, but, as we shall see later, also a more dispersed population and a vast array of roadside businesses.

The automobile necessarily sparked expansion of many supply industries. For example, tires and inner tubes constituted 85 percent of the sales of the American rubber industry during the interwar period. The lifespan of the average tire was extended from three-quarters of a year in 1915 to two-and-a-half years in 1930. Collusion among raw rubber producers forced up the price of raw rubber through the interwar period. American chemical companies responded by developing synthetic rubber, especially during World War II, which proved to be more resistant to wear, oil, and sunlight than the natural product. The automobile also stimulated continuous processing in plate glass manufacture. Ford itself pioneered this method shortly after the end of World War I. Plate glass output tripled in the 1920s. The technology of steel production also improved to accommodate increased demand from the automobile industry with continuous hot-strip rolling from 1924 (Figure 15.2).

After World War I, gasoline for vehicles became the dominant use for petroleum (replacing lubricants and illuminants). Annual fuel consumption per car increased from 473 gallons in 1925 to 599 in 1930, 733 in 1940, and 790 in 1955, in large part the result of increased engine power. Beginning in

Figure 15.2 Road Construction: North Carolina, 1919. The internal combustion engine wrought a revolution in road construction with the introduction of surface-laying machinery.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

1913, cracking techniques (decomposing the heavy hydrocarbon molecules of crude oil into smaller, lighter molecules under high temperature and pressure to make gasoline) lowered the price at the pump. The expansion of demand for gas prompted global exploration for oil. The gasoline yield per barrel of oil more than doubled in the interwar period alone. By improving the efficiency of oil refining, oil companies also reduced pollution per barrel. Nevertheless as production expanded, complaints about pollution during drilling, refining, transport, and use multiplied, leading to the Oil Pollution Act of 1924, which, though largely ineffectual, set the stage for widespread government regulation in the postwar period. Increased production and lower prices, however, discouraged fuel efficiency and led to the enormous consumption of irreplaceable fossil energy in the twentieth century.

General Motors and Model Diversity

In the 1920s, the car took over the American economy and way of life. Whereas there had only been one car for every 265 Americans as late as 1910, there was one car for every five at the end of the 1920s (compared to only one car for every 43 Britons and one for every 335 Italians). In fact, the US produced 81.6% of the vehicles constructed globally in 1927. A majority of the 23 million cars on American highways in 1929 were owned by rural and small-town drivers. The car was no longer the plaything of the rich, but the everyday tool of the masses.

Yet from the mid-1920s car executives were already beginning to worry about market saturation, especially when many car buyers chose much discounted used vehicles. Moreover, there was a decline in technical improvements in the 1920s (consisting mostly of enclosing the car with a metal roof). The problem was how to induce consumers to buy new. One tactic was the introduction of installment purchase in 1916, reaching three-quarters of sales by 1925. Another was to offer generous trade-ins on the purchase of a new vehicle. Ford, still the giant in sales in the early 1920s, with his unchanging, black, box-shaped Model T, was slow to adopt this strategy.

In the face of the prospects of market saturation and in hopes to displace Ford from the king of car makers, General Motors adopted a more revolutionary new approach to car making and marketing. Instead of offering a basic car at rock bottom prices as did Ford, GM chose to emphasize style over technological innovation.GM had been founded in 1908 by William Durant who bought out a number of car and parts manufacturers over the years, including Chevrolet in 1914. However, poor marketing and financial decisions led to the company's takeover by Dupont and investors in 1920. The speculative Durant was replaced by the MIT-trained manager, Alfred P Sloan (CEO from 1923, retiring in 1956). In 1924, Sloan decided to challenge Ford's Model T with a revamped Chevrolet even though it cost $550 to Ford's $290. He was successful, leading Ford to abandon his beloved Model T in 1927 to retool and introduce the far more modern Model A.

Sloan had discovered that Americans would pay more for a car with a modern transmission and other improvements over the Model T, but mostly with style. This began with a more refined body (eliminating the obviously bolted on parts of the Model T), rounded fenders and roof line, and strikingly colorful 'Duco' body paint. By 1927, Sloan had created at GM a style department that was led by Harley Earl, a flamboyant designer who had customized cars for Hollywood celebrities. Earl's guiding idea was to make cars that were lower and longer, rather than boxy as had been the vehicles of the past. Even more important than style was the introduction of obsolescence—each year making often slight changes in the appearance of fenders, headlights, and upholstery. These style changes not only created interest in new models but also made owners of older cars feel outdated and in need of a new vehicle, even if the old one was still functional. This led to the 'annual model change' that overcame the threat of market saturation. GM also offered many distinct models and colors to appeal to individual taste. Ford had succeeded when Americans were buying their first car and many had wanted utility and did not care if their Model T looked like millions of others. By the 1920s, with rising incomes, access to installment purchase, and an ability to trade in an old car, Americans were beginning to demand the style, individuality, and novelty that GM offered.

Sloan also took Durant's hodgepodge of auto brands and offered them to the public as a 'full line of cars' with distinct price ranges and features rising from the 'entry' level Chevrolet, up to the Pontiac, Oldsmobile, Buick, and, at the top, the Cadillac. In theory, this ladder of cars provided Americans with a measure to mark success in life as presumably buyers moved up with age and income from the Chevrolet to the Cadillac. The car had become a measure of status in a country where incomes rose along a long slope. GM took advantage of this by placing its car brands along a rising price incline, offering Americans a way of marking their position on the climb upward in status. In all, this strategy made GM the dominant car maker in the US by the mid-20s to 2008.

Seeing the writing on the wall, Ford flattered GM's Sloanism by copying it. Not only did Ford adopt frequent model changes after 1927, but he formed the Mercury division in 1929 as the mid-priced car and made Lincoln (acquired in 1921) its luxury vehicle, to create his own full line of cars. When Walter Chrysler (formerly of GM) bought the Dodge Company late in the decade, he immediately turned his attention to the creation of the economy Plymouth line so that his company too would have a range of cars. Other manufacturers tried the same strategy but with less success.

Sloan was also a leader in corporate organization. GM combined semi-independent divisions that produced each GM vehicle brand with centralized finance, research, and advertising. The divisions could share information and the costs of parts production. The stability of the company was also aided by the divisional structure: Shifting consumer tastes might cause a precipitous drop in the sales of Pontiacs or Chevrolets but would be unlikely to hurt all

GM cars at the same time. This plan was not only copied by Ford and Chrysler, but by firms in a variety of American industries. The marketing and corporate strategies of GM became even more decisive after World War II. Even though the pent-up demand after World War II, gave small producers like Henry J. Kaiser and Studebaker opportunities, the advantages of mass advertising, dealership networks, and name recognition assured the continuing dominance of the big three, especially GM.

Automobile Culture and the Transformation of American Space

Probably no consumer product has shaped twentieth-century personal life more than the car. The automobile fit particularly well into American culture, where ideals of equality, mobility, and individuality prevailed. At the same time, the car transformed that culture introducing Americans to new ways of shopping, vacationing, homemaking, socializing, and even growing up.

The American automobile began as a hand-crafted luxury. But with the Model T and assembly line, the car began to be accessible to the 'great multitude.' According to Henry Ford, the automobile should be "large enough for the family, but small enough for the individual to run and care for. … It [was] so low in price that no man making a good salary [would] be unable to own one—and enjoy with his family the blessings of hours of pleasure in God's great open spaces."[2] The car, Ford believed, should be available to at least hard-working Americans, not just the rich. The automobile also was to bring autonomy. It was a mass but family-based technology that allowed its owners to escape urban congestion and pollution.

By the 1920s, European factory laborers envied their American counterparts who could share in the good life of automobility when European auto workers could scarcely afford bicycles. The assembly line promised to provide high wages and free time (especially with Ford's five dollar/eight-hour day). Efficiencies in production lowered prices and thus gave ordinary people access to the luxuries formerly available only to the privileged. All this constituted what was known as 'Fordism.' It was more an ideal than a reality for many workers, but the rigors and boredom of mass production work was often compensated by the freedom of that car waiting in the plant parking lot, when its owner got off work. 'Sloanism' with its stress on continuous style innovation, model diversity, and a full line of vehicles seemed to offer even more. This included the promise of a wide range of choices, a positive way to assert identity, and an opportunity to display status as the driver moved up the car hierarchy. The auto promised both mass access and class distinction that simultaneously democratized American life and reinforced a status system (Figure 15.3).

The early car in America was not a mechanical extension of the luxurious carriage as it was in Europe. Rather, it was the successor to the common horse that long before the car had been associated with freedom from constraint.

Figure 15.3 The first recorded traffic jam occurred in 1916. City planners scrambled to keep up as automobile sales soared in the 1920s.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

In fact, despite the technological advance of the internal combustion engine, in the early years, the car was often linked to nostalgic dreams of pioneer-era individualism, especially the cowboy on his horse. It was an alternative to the crowds and need to watch the clock and timetable of train passengers. Sitting behind the wheel and a powerful engine gave the driver the same feeling as sitting atop a horse, reins in hand, but with a lot more 'horses' in control. Men especially understood the car this way. It compensated for a loss of craft, agricultural, and business skill in an age of salaried employment in routinized jobs. Men often enjoyed mastering knowledge about and upkeep of their cars. Males sometimes tried to assert their sense of superiority by making fun of women drivers despite significant female mastery of early automobiles and their operation. And working-class men especially preserved a measure of dignity behind the wheel and working under the hood. Some relished the dream of the freedom of the 'open road' where the burdens of family, work, and even one's own cares evaporated.

Yet, those feelings often were illusory. The car tied its owner to an often unsatisfying job and to a web of responsibilities (servicing, repairing, and purchasing cars in a commercial environment where the used car salesperson and mechanic often took advantage of consumers). More importantly, the ecstasies of motorized power and freedom were countered by the fact that cars crashed and required drivers to submit to a tight regime of rules designed by the authorities to minimize accidents. American 'citizenship,' in the auto age, notes historian Cotton Seiler, meant both personal liberty and severe constraint. Yet Americans were unusually permissive (in comparison with Europe) in regard to the right to drive. Governments were slow to demand driver's tests in the early years and comparatively tolerant of the very young driving—allowing even 14-year-olds to be licensed in more rural states while Europeans insisted on the age of 18. By the 1950s, however, 16 became the normative age (still relatively permissive). Drivers' education courses became common in American high schools. Teens, eager to get behind the wheel, were repeatedly warned of the dangers of driving.

American car culture even shaped the coming of age of American youth. For generations, a major event in growing up was winning the drivers' license and the freedom that it brought behind the wheel. This was nearly unique in the US, where, because of the early and large supply of cars, used vehicles were cheap and readily available. Elsewhere, teens walked or took buses or trains. Even in industrial Europe, the lives of youth worlds were confined to family neighborhoods and mass-transit routes. Despite the Depression in the 1930s, youths could buy an old Model T for as little as five dollars. Successive generations of cars found eager teen buyers. Adults let youths behind the wheel—even those too young to drive legally—especially in rural areas. The 12- or 14-year old (who formerly drove or rode a horse) was often essential as a driver of a farm truck or tractor.

From about 1900 until the 1930s, Americans of all ages took pride in their ability to modify and upgrade their often basic vehicles, adding luggage carriers, lighting, and heaters, sometimes years before these improvements were factory installed. The young adopted this practice after 1930; but they often customized their vehicles, not for comfort or convenience, but for speed. Because of the relative simplicity of the Model T and low cost used, youth could easily 'soup it up' with lightweight pistons and aftermarket carburetors. When they eliminated 'unnecessary weight' like the roof and even seats, youths could make this relic from the 1920s race at 70 mph or more instead of the 40-mph maximum that it was originally designed to run. These hot rods became an important part of the culture of working-class teens in the late 1930s. The more affluent youth, by contrast, borrowed cars from parents or owned newer vehicles for displays of social status and social engagement at dances and parties. The car and its use marked class differences and later with the rise of the Latino low rider car, the automobile marked ethnic difference (Figure 15.4).

Youth car culture became also the setting for the learning of gender roles and for sexual initiation. The 'date,' a form of courtship conducted in public removed from the prying eyes of parents and family, was largely new in the twentieth century. The auto was the ideal setting for dating, giving young couples freedom from the home and neighborhood. The car made possible a special form of privacy, sometimes for 'necking'—in the enclosed vehicle usually by cover of night. The motor vehicle, usually owned and driven by the male, reduced female control over her relations with the opposite sex. Teens also found freedom to socialize without adult supervision in the practice of cruising that emerged after World War II, where youths took over public roads and drive-ins in their cars.

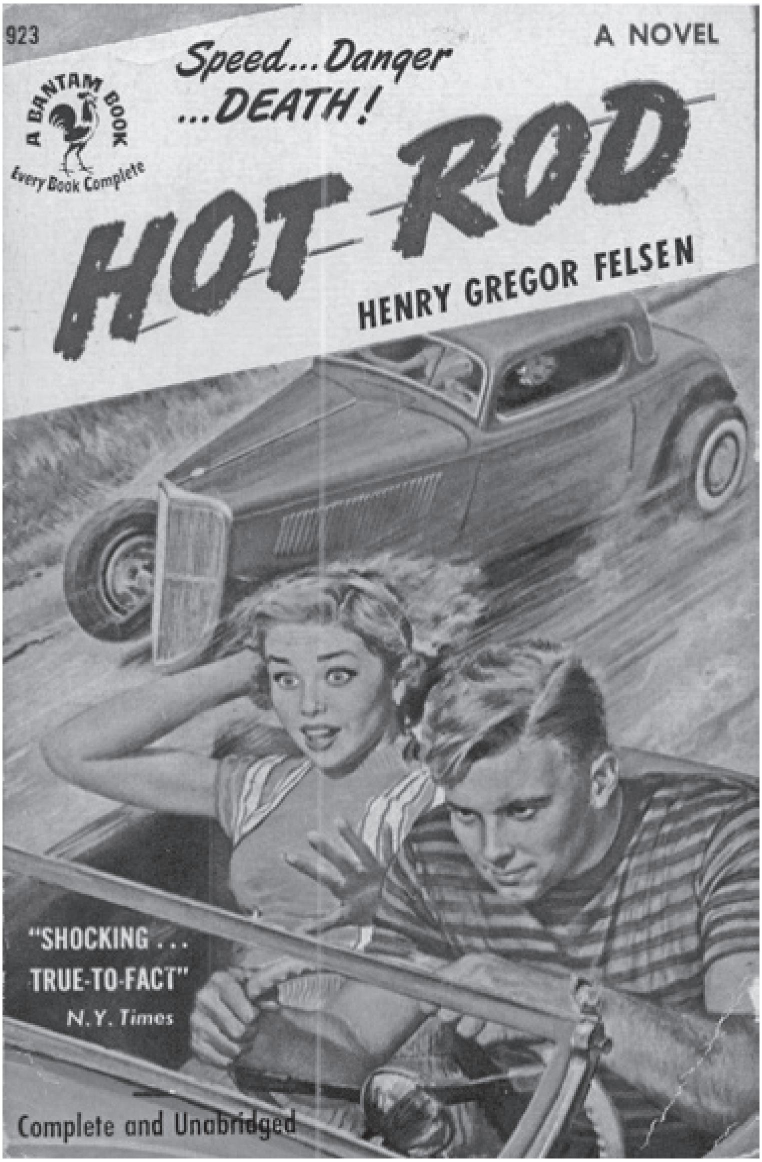

Figure 15.4 The cover from a popular teen novel of 1950, telling the story of a young man's learning to curb his enthusiasm for fast cars and racing.

These practices declined from the late 1970s due to pressure from law enforcement, the increased expense of driving, engine and body innovations that made customizing much harder, and the fact that teens found alternatives to the car to express themselves and socialize (e.g. smartphones). Still, so important is this car ride into adulthood that the automobile culture has become a stand-in, a shortcut in what millions of Americans remember about their coming of age. This led to the nostalgia so apparent in modern old car shows and numerous TV programs.

While the automobile reinforced American values of equality and autonomy and shaped what it meant to grow up American, the car also transformed the American landscape and how that landscape was experienced. By the 1920s, the car had freed crowded cities from millions of horses—and the ten to twenty pounds of manure that each of them dropped on the streets every day. Motor-powered vehicles were faster and took up less space than horse-pulled wagons. Thus, for a time, cars actually reduced congestion in central business districts. While faster cars drove pedestrians and playing children off the streets, the automobile encouraged the paving of urban streets, and led to far greater flexibility in transportation than the train and trolley could ever provide. Beginning in the 1920s, the trolley systems of the cities were losing customers. Decreased revenue led to poor maintenance, and spiraling decline in service that ended many trolley systems by the 1960s. Buses, powered by the ICE, proved in many areas to be cheaper than the trolleys tied to their overhead wires and often tracks. The building of arterial roads offered residents in the increasingly far-flung suburbs speedy travel with limited stops for cross-traffic and traffic lights that made these journeys safer. But all this made Americans more dependent on the automobile.

With improvements in roads, auto touring attracted thousands of Easterners to picturesque New England towns in the summer and to the Florida seashore in the winter. By the 1920s, auto travelers throughout the country regularly encountered the roadside 'tourist trap' of pseudo-quaint museums, whimsically designed gas stations, and 'dinosaur parks' to amuse the children. Mass car ownership also stimulated summer family vacations to national parks, especially in the West. During the 1920s, such visits increased fourfold. Auto camping became a cheap and convenient way of 'communing with nature.' 'Ma and Pa' cabin camps catered not only to traveling families but to couples seeking a few hours of privacy. Thanks to the rise of the interstate highways, chains of motels gradually displaced the small-time motor courts on the old roads. Perhaps bland, but definitely predictable and reliable service could be found at these chains. This was a fact that was discovered by Kemmons Wilson, a Tennessee house builder, who built his first Holiday Inn in 1952.

The car affected a whole range of consumer and leisure experiences. The drive-in restaurant first appeared in Dallas, Texas, when Jesse Kirby opened his Pig Stand in 1921; from the 1940s, these drive-ins (often providing 'car-hop' waitresses) became haunts of millions of adolescents and their cars; by the late 1960s, their disorderly ways drove away families and largely destroyed this colorful institution. Nevertheless, McDonald's restaurants—opened first in Southern California in 1937, to become a national chain in 1954 when bought by Ray Kroc—was one of many chains of successful family-oriented fast-food outlets accessible mostly by car. As early as 1933, the first drive-in movie appeared in New Jersey; by the early 1950s, four thousand of the big screens stretched across suburban American fields. They offered cheap teenage films to romancing youth and children's fare accompanied with playground equipment. In 1955, another offshoot of the automobile was opened—Disneyland. It was located along the Santa Ana freeway and was accessible to the sprawling network of highways that linked suburban Southern California. Disneyland became the model for a new generation of amusement parks, which replaced the old Coney Islands with their links to the outdated streetcars and trains.

Parking costs, due to the high price of land in downtown business districts, forced major mail-order retailers like Sears to construct stores in suburban roadside tracts with large, free parking lots. Kansas City's Country Club Plaza, built in 1923, was probably the first shopping center of the auto age, complete with gardens, and architecture that recalls Seville Spain. From the mid-1950s, the shopping mall began to replace downtown shopping districts that had been serviced by the convergence of rail and street car lines. Located along arterial streets and later adjacent to freeway exits, the shopping mall served the car-bound suburbanite. The Austrian émigré Victor Gruen built the first fully-enclosed climate-controlled mall (Southdale in suburban Minneapolis) in 1956. Some became very large (like Mall of America, opened in 1992). Gruen was disappointed that the mall did not also become a place of community. While some malls closed after 2000 because of declining crowds due to security issues and the rise of internet shopping, they remain distinguishing features of American consumer culture. At least as typical was the roadside commercial strip, with its gaudy neon signs designed to attract fast-moving cars to its fast-food chains and discount stores.

Perhaps most important was how the automobile encouraged suburban sprawl in the twentieth century. A parkway (first built in New York in 1911) made it possible for city workers to live 'in the country.' This trend culminated with the Interstate Highway System (begun in 1956), which facilitated a vast rush to the suburbs. As we saw in Chapter 8, the American suburb was not merely the product of transportation technology; rather, it had roots in the 'pastoral' ideal and the quest of wealthy Americans to escape the industrial city. In the twentieth century, the suburb became accessible to the less affluent, thanks in large part to the car and bus. In the 1920s, for example, Los Angeles opened 3,200 subdivisions to mostly Midwestern migrants seeking a promised land of sunshine and the joys of suburban living. Los Angeles set the trend for postwar suburban sprawl. Between 1950 and 1970, new suburbs increased the housing stock in the United States by 50 percent, with as many houses again added in the 1970s.

The car and decentralized neighborhoods encouraged new ideals of domestic space. The car culture led to the disappearance of the Victorian-era home with its front porch, from which people would greet neighbors out on evening strolls. Just as the porch declined, the attached garage appeared. Car owners could build suburban houses on larger lots than were available in cities because of lower real estate prices on the periphery of urban areas. Thus, from the 1930s, 'space-wasting' one-story ranch houses replaced two-story Victorian homes. The mass-produced Cape Cod and ranch houses were quickly erected in hundreds of Levittowns and Daly Cities immediately after World War II.

The sprawl caused by the car also tended to sunder the traditional links between city and suburb: The long-term trend was for suburbanites both to work and play on the periphery of the city in industrial parks, commercial strips, and shopping malls clustered around freeway exits. This development, critics argue, reduced the cultural diversity and economic vitality of urban centers. It also created the long commute in rush hour—even across suburbs on the city's edge. By the 1980s, the expanse of 'high tech' firms and suburbs that blossomed in the Silicon Valley of Santa Clara County in California, for example, meant 45-minute journeys to commute a mere six miles.

The car culture not only dispersed work and consumption but indirectly transformed living space. Homes got larger in the 1960s as newer suburbs were built on cheaper, more distant lots, often one-third of an acre or more. One inevitable addition was the family or 'recreation' room for domestic

Figure 15.5 A postcard advertising one of thousands of family motels in the 1950s before the dominance of motel chains. Note the large sign to attract fast-moving cars and the separate entrances for each customer's vehicle.

Credit: *Boston Public Library, Wikimedia.*

togetherness. Homeowners displayed their skills and taste to their neighbors in their gardens and home additions. All this went beyond 'keeping up with the Joneses.' Gardening and carpentry were also forms of self-expression for those whose work seemed to be unfulfilling and demeaning. Nevertheless, the retreat to car and home may have also reduced contacts with people from different income or ethnic communities, or even with neighbors. Suburbanites drove home on their sidewalk-free streets, pushed the remote garage-door openers, and entered their kitchens, seldom encountering neighbors. Still, many found the suburbs to be 'oases' free from intercity violence.

The Peak and Decline of American Automobility: 1945 to the Present

For the 15 years after World War II, the American-made car, led by GM, was king in the United States. Vehicles became longer, lower, and more addicted to style, but also increasingly less efficient and obsolete more quickly. By the 1960s, but particularly after the oil crisis of 1973 when gas prices spiked, smaller, more efficient imports began to move in. American manufacturers gradually downsized but were unable to abandon many traits of Sloanism and after 2008 experienced a major decline.

After years of sluggish sales due to the Depression and suspended production during the war (1942–1945), Americans were eager to buy new cars. In the years immediately after the war, the US dominated world production of cars and much else. Pent up demand and eagerness to return to the prosperity of the 1920s led Americans to buy increasingly large cars with high-compression engines but also that frequently were modified in style. New cars had larger windows and taillights and added flourishes like the tailfin. Car advertisers appealed to men by associating the car with American military might (like the Oldsmobile 'Rocket 88' of 1949 with its overhead valve engine).Car makers told women about their colorful upholstery and soft rides (compared with living room furniture and women's fashion). Manufacturers that promised economy and efficiency like the Nash, Henry J, Kaiser, and Studebaker found it hard to compete with the Big Three, especially GM. In the early 1950s, the less affluent purchased used Fords and Chevrolets rather than new Nash Ramblers. And the broad middle class took advantage of stretched out car loans and trading in their older cars for the latest model. The result was that by 1958 turnover on cars dropped to 2.5 years and cars were on the road three years less than in 1941. Authors like Vance Packard complained in 1960 that American car companies were "waste makers," producing vehicles that were designed to wear out more quickly than in the past. 'Planned obsolescence' was built into the frequent design changes that made even cars that had years more of utility appear outdated within a couple of years. Disenchantment with Sloanism produced a market for the Volkswagen at the end of the 1950s. Nicknamed the Beetle, the Volkswagen promised the opposite of what the Big Three delivered: Economy, only practical innovation from year to year, and ease of driving. The Big Three responded in 1960 with compacts (the Corvair, Falcon, and Valiant) that were cheaper, smaller versions of their 'full-sized' Chevrolets, Fords, and Plymouths. Within a few years, however, these compacts expanded in size to be indistinguishable from standard American cars or became discredited for their poor design. Americans were reluctant to accept the small utilitarian car. In the 1960s American cars got bigger and engines more powerful with the astonishingly high horsepower offered by the muscle cars. Beginning with the Pontiac GTO with its 325 horsepower engine, by 1970, these factory hotrods offered more than 400 horsepower engines and appealed especially to young males. The rise in gasoline prices following the oil embargos of Middle East producers in 1973 and 1977 led to a second invasion of imports, this time from Japan. Detroit grudgingly produced smaller cars. However, these downsized American vehicles were of mixed quality; and Toyota, Datsun (renamed Nissan), and Honda gradually gained loyal buyers for their reliability and price. As early as 1970, the US held only 36 percent of the world's car market compared to 76 percent in 1953. This was just the beginning of a long slide.

Unsafe cars led to an increase in road fatalities from 30,246 in 1948 to a peak of 54,589 in 1972 (though there were more cars by the 1970s). Pollution from exhaust contributed to smog and American automobiles averaged only 13.5 miles per gallon of gas (MPH) in 1975. Federal laws required seat belts and catalytic converters to control exhaust emissions in 1965. Also in 1975, Congress demanded that car companies raise the MPG of their passenger car fleets to 27.5 within a decade. The standard for a light truck was only 19.5 MPG.

While American cars gradually became safer, smaller, and better made (dramatically increasing the longevity of most models), Americans were not quite ready to abandon Sloanism. The loophole in the fuel efficiency standard of 1975 led to the dramatic growth in the demand for minivans and Sports Utility Vehicles (SUVs)—which fell under the lower efficiency standard for light trucks. As gas prices stabilized and even declined (to pre-1973 levels when adjusted for inflation), the gas-guzzling SUVs captivated the American public. Fuel price increases and the recession of 2008 deflated American zeal for monster SUVs like the Hummer, but the SUV came back in the 2010s, displacing the utilitarian compacts. Moreover, while the Sloanist culture of big high-powered cars remained, Americans had hardly abandoned other aspects of Sloanism—including frequent style changes and the 'full lines' of cars that had made GM so successful for decades. While GM's status ladder had collapsed with the disappearance of the middle rungs (the Pontiac and Oldsmobile), it and other car companies (including the imports) still offered a full range of vehicles from 'entry level' models to 'top of the line' luxury for those who have 'arrived' and want to display it. The introduction of hybrid ICE-electric cars and the increasing availability of 'plug-in' electric cars are only beginning to challenge more than a century of dependence on fossil fuel.

If Americans have been reluctant to abandon Sloanism, they have fully embraced another long trend—the personal car. Until the 1960s, only 15 percent of American households possessed more than one auto; most had to make do with a family vehicle that had to be shared by the whole household. In the mid-1960s, however, a new attitude about cars was shown by the popularity of the Mustang and other 'pony cars.' These vehicles were designed for young singles attracted to highly individualized styles and models. The arrival of small luxury vehicles, especially BMWs in the 1970s appealed to the individualism of young urban professionals who had delayed or rejected family life. Many others followed.

By 1970, 28 percent of households had two or more vehicles. By 2012, only 34 percent of families had only one, while 31 percent had two and 35 percent had three or more. The growing expectation that each person of driving age should have access to a personal vehicle (along with the rise of married women in the workforce in need of a car to commute) explains this trend. Many families have vehicles for going to work, for play (sometimes a pickup truck, SUV, or sports car), and even for hauling the kids (a minivan). As with other modern machines like TVs, and computers, the car has become less a vehicle of family togetherness than a means of personal expression and autonomy. By 2014, there were 797 cars for every 1,000 Americans. In Britain the number was 519, China, 205 and in India, 32.

The car has never been a greater part of American life. Yet, there may be signs that the obsession with auto-mobility may be on the decline especially among the young. The percentage of American 16-year-olds holding driver licenses dropped from 43.8 percent in 1998 to just 24.5 in 2014. New laws made obtaining the once coveted license at sixteen years of age far more difficult and, as noted above, increased cost of driving has discouraged young drivers.

The automobile has had a complex impact on Americans: It offered them privacy in travel, but also a way to display wealth, taste, and personality. The car widened residential choice, even as it forced Americans into hours of traffic to get where they wanted to go. The auto symbolized the American solution to industrialism: Accepting a sometimes dehumanizing job in exchange for the income and time to participate as an individual in the car culture. The car has produced a dependence on the gasoline engine even as it makes possible personal mobility and privacy. The results do not please all, especially those longing for a society more sensitive to urban and social values. But most Americans remain happy with (if perhaps addicted to) their cars.

Notes

1 "Motorists Don't Make Socialists, They Say: Not Pictures of Arrogant Wealth, as Dr. Wilson Charged," *New York Times,* March 4, 1906, 12.
2 Henry Ford, *My Life and Work* (New York: Doubleday, 1922), 49.

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16 Mechanizing Sight and Sound

The Second Industrial Revolution brought not only the mass production of durable goods, but also the mass production of culture. Art and entertainment, which had traditionally been experienced in unique images and performances, increasingly was replicated on mass-distributed recordings or film, and was broadcast to audiences of millions. What once was preserved imperfectly (or imaginatively) in paintings and drawings was captured chemically exactly as seen by the eye. Culture, formerly enjoyed in lively groups on rare occasions, was in the new age of telecommunications experienced in the privacy of homes or dark viewing rooms, often daily. Culture that was local became national, even global. A series of inventions, mostly from the late nineteenth and first half of the twentieth century, transformed the meaning of arts and entertainment. We will begin with the mechanical and chemical innovations of the phonograph, photograph, and motion picture in this chapter, which will be followed by the electronic media of radio and television in the next.

The Phonograph

The desire to capture and reproduce the voice has obsessed people for centuries before Thomas Edison invented the phonograph. Similar dreams crop up again and again until the 1840s, when the German-American Joseph Faber tried to produce artificial speech from an ivory reed attached to a rubber tongue and lips controlled by a keyboard. In 1877, the practical Edison happened upon a very different way of producing voice while attempting to develop a device for recording telegraph messages. At high speeds, this machine made a noise as it attempted to recreate the dots and dashes of Morse Code. Drawing on the just-invented technology of the telephone, (see Chapter 10), Edison found that sound waves vibrating a diaphragm could be used to cause a stylus to make depressions in common materials such as paper or tin foil rotated on a cylinder. When that stylus was placed in the just-recorded groove and turned on the same cylinder the diaphragm vibrated, reproducing his just-spoken words. With this simple device for copying and replaying short voice messages, Edison hoped to replace the tele*graph* repeater by a tele*phone* repeater, allowing the transmission of a recorded voice rather than a coded message. As amazing as audiences found this device that captured and preserved the human voice, the first phonograph was a step back from the telephone. Edison's phonograph of 1877 transmitted sounds by purely mechanical means—with no assistance from electricity or magnetism (innovations that would have to wait for more than 40 years in the phonograph) (Figure 16.1).

Edison saw many possible uses for the device: Dictation, recorded music, and even telephone answering machines. He appears not to have appreciated the commercial potential of his device in home entertainment, however. By 1878

Figure 16.1 The young Edison displaying his 1878 cylinder phonograph.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Edison was excited about the possibility of electric lighting and its commercial possibilities; so he dropped work on the phonograph for the next decade.

Alexander Graham Bell had a clearer view of the potential of the phonograph. With his cousin Chichester Bell, he set to work on improving the device with a waxed cardboard cylinder to replace Edison's tin foil record. When Edison learned of Bell's work in 1887, he sued Bell with patent infringement and returned to improving and marketing the phonograph. Although Edison went on to manufacture phonographs and records, he lost legal control over this technology. Within a few years, other companies, especially Columbia (1893) and Victor (1901), challenged and ultimately prevailed over Edison. Here, as in the electric illumination and, as we shall see later, the movie business, Edison failed to dominate industries he played a large part in founding.

At first, Edison emphasized the potential business uses of his device, developing a successful line of dictation machines for the office in the late 1880s. As would later happen with radio, consumers pointed out market potential that innovators had not appreciated. Showmen at fairs attracted large crowds to listen to the as-yet far from perfect sounds of the phonograph. In response, Edison followed others into the production of both jukeboxes and home phonographs in the 1890s, and concentrated innovative effort on sound quality.

Much of the effort of early phonograph producers was devoted to providing a power source to turn the recording. Batteries and small electric motors were too expensive and impractical for the mass market in the early days of electricity. In the 1890s other firms produced cheap machines relying on spring-motors, and Edison was forced to duplicate their efforts.

Improving the phonograph proved more difficult than its original conception. It was only in 1900 that Edison found a way to mass-produce records instead of fabricating small batches of cylinders in repeated live recordings. The original recording was used to create a negative mold in which the grooves of the recording could be represented by raised surfaces on the inside of the mold. The negative could then be used to mold a large number of replicas.

Edison's cylinders, however, found competition with the flat discs that had first been introduced by Emile Berliner in 1887. The needle moved from side to side within the grooves on the disc rather than up and down as on the cylinder. Discs were also cheaper to stamp out and easier to stack and store. Just as Edison stuck with direct current when others embraced alternating current, he remained with cylinders, losing market share to Victor, which soon after 1901 became the dominant producer of disc phonographs and records. Though Edison added high-quality discs to his product line in 1912 and continued to manufacture cylinder recordings, he finally went out of the phonograph recording business in 1929.

In the beginning, both recording and playback could only be accomplished acoustically. That is, a cone-shaped horn was used to channel sound waves to the point where the diaphragm was located. When reversed in home playback, the horn would amplify the sound from the stylus in the groove and diaphragm. Sound quality was limited. Only fairly loud, uncomplex sounds tended to get recorded. Operatic voices produced acceptable recordings, but not full orchestras. Bass frequencies were missed. Many found the horn ugly, especially in the parlor. This led Victor to develop the Victrola, a phonograph where the horn was built within a fine wooden cabinet and hidden to fit nicely with other respectable home furnishings.

Despite the growing sophistication of the acoustic phonograph, inevitably the phonograph followed the radio with electronic recording and amplification. And this would be marketed fully in 1927. Electric recording (replacing the horn with an electromagnetic microphone) increased the sound range by two and a half octaves over acoustic records. In time, sound engineers manipulated the volume and tone gathered from multiple microphones to record a sound that was 'superior' to the live concert experience. An electromagnetic stylus on the phonograph converted the sound waves emitted from the record's grooves into electronic signals that were amplified through radio tubes (that will be discussed in the next chapter) and reconverted to sound via electromagnetic speakers. All this eliminated the tinny sound of the old system, allowing the phonograph industry to compete with the newly introduced radio.

In 1948, Peter Goldmark at Columbia Records replaced the common shellac record with vinyl, creating the microgroove long-playing (LP) record that revolved 33 1/3 times per minute instead of the 78 RPM of the old records. This made it possible to listen to 20 minutes of music per side instead of the single song of 3 or 4 minutes. This led to the modern album with full recordings of symphonies and musicals, for example. RCA developed an alternative format, the 45 RPM record that could be stacked on a wide spindle that automatically played a succession of recorded tunes. This format became popular with youth who wanted to hear a variety of short songs recorded individually on their '45s.' These records were perfectly suited to recordings of rock 'n' roll songs that emerged by the mid-1950s. Stereo records and phonographs (that recorded two tracks of sound simultaneously giving a broader sound) appeared by 1957. From the beginning, stereo attracted the audiophile with the sophisticated ear and a taste for 'hi-tech' gadgetry. Recording technology divided listeners into rather distinct communities of taste and age.

Mechanized Sound Changed What and How We Hear

The phonograph was first conceived to retain very particular voices (useful in dictation in the office or preserving the voice of a famous person or relative). But by the 1890s the phonograph became a mass-produced device, designed only to play back prerecorded commercial music and speeches mostly in the home. It was one of many new domestic appliances that emerged about this time that accompanied home electrification (vacuum cleaners, electric stoves, and irons, for example) and followed earlier domestic appliances like caste iron stoves and sewing machines that eased housework.

The phonograph brought more. It *privatized* pleasures that formerly had often taken place in public places and social gatherings like concert halls or cafes. And it also introduced a national, even global culture to the individual sitting in the living room through the commercial record that was distributed to the far corners of the nation. In the privacy of the home, a person from Butte Montana could hear the great Italian tenor, Enrico Caruso, sing opera. Before this time, such music was available only to those willing and able to attend public performances in New York or even Milan Italy. By 1900, instead of recording the voice of some beloved family member, the phonograph in tens of thousands of homes reproduced the voice or music of a celebrity, a person partly created by this new technology (Figure 16.2).

The phonograph also dramatically enhanced personal choice as records quickly offered the widest possible range of music—from the highbrow sound of opera to popular tunes and comedy routines. And with little effort, the listener could switch from one recording to another. The phonograph record both uplifted taste (the goal of Victor's Red Seal recordings of internationally renowned singers and instrumental soloists), but Victor also offered consumers the widest range of popular music, from college fight songs and Hawaiian folk tunes to African-American blues and jazz. With the phonograph record, sounds and voices were pulled from their original social context (a concert hall, church, or bar) and time (as music from the time of Mozart or a medieval church) and made them part of personal life. Recorded music was and is often heard as 'wall paper' background sound, often shaping mood while the 'listener' did something else.

The record player became a particularly modern type of commodity. Manufacturers continuously upgraded the phonograph, attracting consumers who sought the cutting edge of technology. Victor's Victrola of 1907 and Edison's four-minute Amberol record of 1908 encouraged consumers to expect more and more. Shoppers learned that last year's technology was obsolete. Manufacturers also offered a wide range of devices at many 'price points' from the entry phonograph that introduced children to recorded sound to luxury models that attracted the well to do. Both strategies anticipated the 'annual model change' and 'full line' of cars that marked the American automobile industry by the 1920s and the smartphone industry today. The phonograph and record also became an early instance of 'razor and razor blade' marketing: Manufacturers like Edison and Victor sold phonographs (the razor or hardware) primarily to create a market for the regular purchase of recordings (the blade or software).

Perhaps the greatest impact of the phonograph was to introduce the modern music form of the short-lived 'hit.' The recording produced a new type of sensory experience: Two or three minutes of musical pleasure consumed in about the same time it took to smoke a cigarette or eat a candy bar (other hits of pleasure that emerged at this time). The recording industry replaced sheet music as the main way to disseminate mass-produced popular music at

Figure 16.2 A publicity photo featuring Victor's Italian star tenor, Enrico Caruso, beside Victor's Victrola, ca. 1910, promoting the dream of ordinary Americans sharing the voice of an international personality.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

the song-writing 'factories' of Tin Pan Alley in New York. Success for both Victor and Tin Pan Alley required the selling of 'hits,' usually simple, topical, and 'catchy' ditties that attracted a mass audience seeking to keep up with the times. In a short time, such tunes were widely played, often to the point of satiation. Because success was impossible to predict and because they were 'turned over' quickly, there had to be a continuous flood of songs. This produced an on-going expectation of novelty that marks modern popular culture. Curiously, this novelty culture also led to nostalgia for the music of the continuously-changing past. As people aged, they identified specific songs and artists with their youth, a brief period when these tunes dominated their soundscapes. A middle-aged person young in the 1900s longed to hear the 'hit' of that time ("Shine on Harvest Moon," for example), just as an aging baby boomer in the 1980s, still swooned over the Beatles song, "Hey Jude" (1968). 'Oldies' inevitably accompanied novelty. The phonograph shifted popular culture in subtle ways.

Photography and Motion Pictures

If records mechanically reproduced sound for millions of listeners, photographic film did the same for visual images. Photography is in a sense quite simple: Once light-sensitive substances were discovered, it became possible to point a device (called a camera) at a person or scene and to capture this exact image from its reflected light on a specially-treated photographic plate. The photograph camera was based on a centuries-old scientific curiosity: An upside-down image of an exterior scene (a person, building, or landscape) can be projected on the interior wall of a darkened room (the Latin meaning of the term *camera obscura*) from the light of a pinhole on the opposite wall. When this 'camera' was miniaturized as a box, the reflected image on one side of the camera could be traced, producing a copy of a scene. Inevitably, inventors sought ways of recording a more perfect replica chemically. Nicéphore Niépce of France produced the first successful photograph in 1827 using a photosensitive form of natural asphalt. Exposure was too slow to be practical, however, and Niépce had no way to 'fix' the image by stopping the chemical reaction. In 1835 his younger partner, Louis Jacques Mandé Daguerre discovered by accident a new technique: he treated a silver-coated copper plate with iodine just before placing it in a miniature camera obscura. Then, after exposing the plate to a scene through a lens for four to ten minutes, and then treating the plate with mercury fumes, a positive image appeared. In 1837, he solved the final problem when he found that a solution of salt in hot water would fix the image, halting the reaction of the light-sensitive material to light. He called the resulting metallic image a daguerreotype, and in 1839 gave the technology to the public in exchange for a French government pension of 6,000 francs per year.

At the same time that Daguerre was developing his photo-plates, the Englishman William Henry Fox Talbot announced a method that involved photosensitive paper that had been soaked in salt and silver nitrate, which would turn dark when exposed to light. The resulting negative image could be treated with sodium thiosulfate to produce numerous copies of the image.

Partly because of the graininess of the paper, Talbot's photographs were not as sharp as Daguerre's.

Both Daguerre's and Talbot's methods were superseded from 1851 by the use of glass plates. Frederick Archer, an English sculptor and amateur photographer, found that collodion (a syrupy mixture of nitrocellulose in alcohol and ether) spread on glass plates served as an excellent carrier of halogen salts, a photosensitive material, which when treated with silver nitrate just before exposure and ferrous sulfate afterwards, produced a negative image on the glass. The negative consisted of dark areas where light had struck the glass—the more light the darker. The photographer would then prepare a sheet of paper coated with silver chloride. The coated paper was placed under the glass negative, which was exposed to light. This yielded a positive image. Thereafter the print was fixed by washing it in sodium thiosulfate. This method could provide images as sharp as Daguerre's and could produce copies as easily as Talbot's. Archer's wet glass method allowed for the mass distribution of photographs, especially portraits of famous people.

However, the process was messy, and the photograph had to be developed immediately after being taken. For the next two decades, photographers searched for a solution to the limits of the 'wet' process that would allow treatment well before, and development well after, the photograph was taken. The answer came only in 1871, when it was found that plates coated with silver bromide salts mixed with celluloid gelatin achieved both ends (dry process) (Figure 16.3).

The American George Eastman soon recognized that the new chemical solution would work as well on paper as on glass. By 1888, he shifted to celluloid film on a roll that could expose a succession of photos. The result was the Kodak camera. It revolutionized photography by eliminating the expensive equipment and cumbersome exposure and development required for early photography. No longer was picture-taking the preserve of professionals. The Kodak allowed the amateur simply to snap the picture. After a roll of film had been shot (containing a hundred round pictures, 2.5 inches in diameter), the whole camera was mailed to Eastman's developing centers in Rochester, New York. "You Press the Button, We Do the Rest," was Eastman's motto. The Kodak was widely advertised to women and even children; the first 'Brownie' Kodak cameras that later became the name for Kodak's economy line were named after a set of popular storybook elves. The company promoted candid photography, especially capturing the antics of small children before they 'lost' their 'cuteness.' These snapshots often replaced the formal family photographs taken by professionals who had used the older processes. By 1900, one in ten people in both the United States and England owned a snapshot camera.

Like Edison with electrical power, Eastman had recognized the advantage of creating an entirely new technological system. By producing cameras and film *and* providing film developing services, Eastman presented customers with an entire photographic experience. His process empowered the individual picture

Figure 16.3 A German photographer posing with his wet collodion camera and equipment about 1858.

Credit: *Hans Seger und Erwin Hintze, Jahrbuch des Schlesischen Museums für Kunstgewerbe und Altertümer Schlesiens*

taker, enriched the Eastman Corporation, and marginalized the middleman professional photographer. And Eastman's researchers continually updated all phases of the process. Eastman Kodak set up its lab in 1913, leading to color film by the mid-1930s (Figure 16.4).

Roll film in photography ushered in motion pictures. However, the first experiments with motion pictures occurred in the 1870s. These were inspired by the long tradition of flash cards, which had established the principle that the eye could be fooled into perceiving motion when faced with a rapid succession of still drawings of an action scene (as in a cartoon).This illusion led to a popular toy, the zoetrope, where a revolving strip of images, was seen as an action scene (such as a figure dancing). As the length of time required for exposure was reduced with film photography, an illusion of a living scene could be created in a rapid succession of photo images.

Thomas Edison saw motion pictures as a potential complement to his phonograph: A phonograph for the eye. When Eastman began using rolls of celluloid film in his cameras in 1888, Edison and others recognized that this film had the potential to operate as a motion picture film as well. Edison's assistant William Dickson developed a mechanism for ensuring the regular movement

Figure 16.4 A typical Kodak snapshot camera ad instructing the mother to capture those special spontaneous events of childhood, rather than a stiff image as was common in the older studio photograph with a camera requiring a long shutter exposure.

Credit: St. Nicholas, *Sept. 1915, 20.*

of a perforated film strip through the camera and its synchronization with the opening and closing of the shutter that let in light through a lens. Edison did not develop a projector, however, even though projected images on screens were featured regularly in the nineteenth-century magic lantern shows. Instead, he had Dickson produce the 'kinetoscope' in which the film was passed in front of an Edison lightbulb. These 'peep-shows' proved popular for a short time when introduced in 1894 to hotel lobbies, amusement parks, and arcades.

Edison's patents limited American innovation over the next years, but he had neglected to apply for international patents (outside of Britain). Thus it was in France, in 1895, that the movie projector was introduced by the Lumiére brothers. Its success there caused Edison and others to produce projectors for the American market beginning in 1896. At first, they saw its use as being part of live vaudeville shows, and the novelty of the motion picture (rather than a story) that attracted crowds to see these short films. Within a decade, however, these movies had become alternatives to live theater.

The possibility that sound might accompany the movie, and thus greatly expand the market, had been recognized from the outset. Dickson had provided the kinetoscope with a phonograph to run at the same speed as the movie. The trick, though, was synchronization: Sound and action had to move at exactly the same speed, and as films became longer such a primitive technique was inadequate because of the short duration of the record. True synchronization could happen only if a sound track could be imprinted on the movie film itself so that the audio exactly matched the video. By 1927, an innovative sound-on-film technique converted sound waves into electrical impulses, which, in turn, modulated the intensity of an electric light, the varying patterns of which were photographed onto a 'sound track' that ran along the film. When a copy of this sound film was placed on a projector at the theater, light shown through the sound track recreated these varying intensities of light, which were converted via a photoelectric cell to modulating electric impulses. When run through an electronic amplifier (based on radio tube technology), these electric signals were converted back into sound waves via an electromagnetic loudspeaker. This made possible both the exact coordination of audio and video as well as the production of sound loud enough to fill a cavernous movie palace. It was expensive to re-equip studios with sound stages and theaters with sound projectors and loudspeakers, but sound movies were the norm by the end of the 1920s.

Soon moviemakers were looking for the solution to the final hurdle, color motion pictures. Even before color film for still photography was available, movies were tinted to gain the appearance of color. In 1935, the Technicolor Corporation introduced the first technique for actually shooting true color film. Because of its high cost, even in the late 1940s only 12 percent of Hollywood films were in color. Thereafter, the end of the Technicolor patent combined with competition from television raised this proportion to 50 percent in 1954, and 94 percent in 1970 (Figure 16.5).

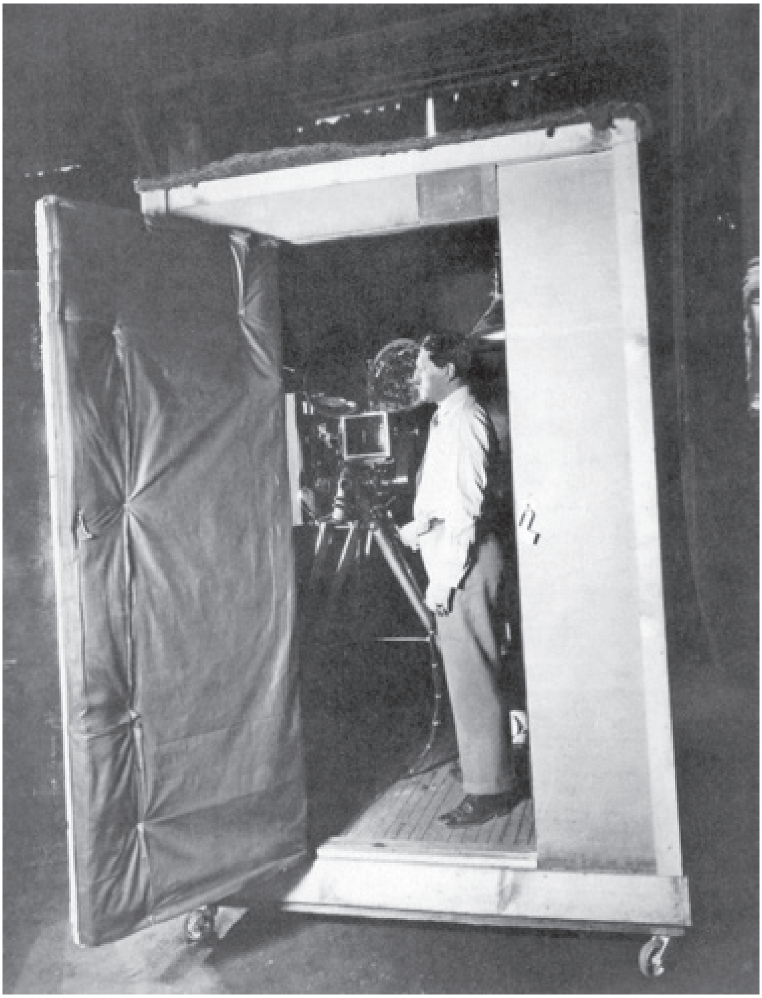

Figure 16.5 Early sound camera, 1926: The camera had to be enclosed so that its own noise would not be recorded. Camera mobility was severely reduced.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Mass-Produced Sights and Sounds: The Impact of the Movies

Most innovations discussed in this book were created to fill a long-recognized need. Although Americans and Europeans had long experienced the projected image (as in magic lantern shows) and had experimented with simulating moving images with parlor toys like the zoetrope, no one at first anticipated that motion pictures would unleash a vast entertainment industry. But the demand for popular entertainment with the increase in income and leisure time created a mass market for the new invention.

Early filmmakers drew upon what ordinary people were used to and liked. Edison's kinetoscope of 1893 offered a short show of acrobatics and other vaudeville acts at penny arcades and similar places patronized by the working classes. The emergence of the projected film in 1896 was at first just another 'act' in vaudeville, not much different from the magic lantern, except for its greater realism because of moving pictures. It featured the curiosity of lifelike action—water splashing on a beach, the execution of a criminal, the illusion of an oncoming train, and the movements of sports heroes. Many early films featured travel themes. Some early cinema offered illusions through the use of techniques like film splicing to make objects or people appear or disappear or the double exposure used in *Uncle Tom's Cabin* (1903) to create the fantasy of angels carrying off the departed. Fairy tale magic was popularized in Georges Mèliés's famous *A Trip to the Moon* (1902), featuring a space ship's landing on the moon. His work became a model for modern special-effects film making. Winsor McCay used cartooning to create whimsy in films like *Gertie the Dinosaur* (1914). This could not be duplicated in live theater. Burlesque sexual teases, also increasingly common on the stage, were copied by filmmakers. *What Demoralized the Barber Shop,* for example, featured a raised skirt and 'naked' calves.

Only gradually did filmmakers begin to see the potential of the movie for displaying new ways of depicting a story: The American Edwin Porter's *The Great Train Robbery* of 1903 used the mobility of the camera and the editing process to film fast-paced outdoor action scenes and tell a 12-minute story involving gun play, fast trains, a heroic girl, and final retribution. Different camera angles added drama and variety. D.W. Griffith fully exploited these techniques in his feature film *Birth of a Nation* (1915) with close-ups, panoramic scenes, and cameras in motion telling the story of the Civil War and its aftermath (and celebrating the notorious Ku Klux Kan). Griffith's motion picture lasted an astonishing three hours and fifteen minutes.

The Nickelodeon (appearing about 1905) offered films to working class people in the backs of cigar stores or abandoned shops. Often priced at a fifth of a ticket to vaudeville, Nickelodeon programs of twenty minutes or so fit well into the busy schedules of workers, often after a strenuous day before taking the trolley home. The fact that many in the audience understood little English was immaterial in these days of the silent film. Working class audiences enjoyed action films and slapstick comedy, with stirring live piano music adding excitement to the inevitable chase scenes. Moralists condemned the 'nickel madness' as corrupting of the morals of women and children, who to the dismay of social elites attended these shows. However, soon others realized that the movies were an alternative to the saloon and film makers responded to potential censorship by self-regulation.

Early filmmakers tried to control, even eliminate competition. As had other industries (telephone, automobile, and radio, for example), leaders of the movie business tried to create patent monopolies. In 1908, Edison along with film companies who had licensed the use of his patented movie camera and other equipment joined with the Biograph Company and for a time with Kodak to create the Motion Picture Patent Company (MPPC). By pooling patents, these companies attempted to create a legal monopoly to control all American production, distribution and exhibition of movies. The MPPC required that films be standardized: Marketed by the foot, changed three times a week at theaters, and sold in bundled 15-minute programs. In 1912, the government filed a suit against this monopoly, winning a court-ordered dissolution finally in 1917. The Patent Association, though, had long before this become irrelevant.

Competitors who offered a more appealing product drove the Patent 'Trust' out of business. The key was providing an alternative to the often cheap and repetitive one-reel movie that the 'Trust' often made. That alternative was the modern 'feature' motion picture. Independent distributors like Carl Laemmle, Adolph Zukor, and William Fox introduced this innovation. They imported European 'epic' movies and film stock to make their own films. Zukor, for example, bought rights to the French-made film, *Queen Elizabeth* (1912), a four-reel picture featuring the famous English actress, Sarah Bernhardt. This was more than a ploy to avoid the patent infringement suits of the MPPC. Zukor realized that a 'respectable' middle-class audience—not just the working classes—could be attracted to the movie theater if they were offered a fully-developed story, similar to the theater.

With the theatrical feature film came the movie palaces, first built in New York in 1913. These plush auditoriums came equipped with ornate lobbies decorated to look like Chinese pagodas or Spanish haciendas. They were built in the downtown shopping hubs of cities or in residential areas near streetcar stops. These movie palaces retained the visual clues of vaudeville and theater, including vestibules, recessed box offices, protruding marquees, and colorful posters. Many were large; some in New York could seat 5,300. They often featured orchestras and uniformed ushers that attracted the affluent and upwardly mobile who were put off by the plebeian look of nickelodeons. The high-end movie houses included organ accompaniment (rather than a piano) and employed ushers dressed in braided uniforms with epaulets. As a result, movie receipts rose from $301 million in 1921 to $720 million by 1929, four times more than all sports and live theater sales. An entertainment that at first appealed to the immigrant working class was broadened to a 'mass' audience of all social strata (Figure 16.6).

Another invention of the independents was the 'star.' Filmmakers who belonged to the Patent Association refused even to mention actors' names (in fear of having to pay 'star' salaries). Independent filmmaker Carl Laemmle recognized that audiences wanted to identify with featured actors who they

Figure 16.6 A classic from the era of the movie palace, the Granada Theater in Chicago about 1933. Note the elaborate walls, balcony, and ornate organ alcove.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

knew only on the screen. He created the first modern film 'star' in Florence Lawrence in 1910. She had earlier acted in Biograph films, where she had been identified only as 'the Biograph Girl.' Lawrence was soon followed by better-known luminaries such as Charlie Chaplin, Mary Pickford, and Douglas Fairbanks who quickly gained a following with personal appearances and interviews in fan magazines that first appeared in 1911. Movie goers, especially the young and female, swooned over and idolized the personalities of actors, closely following their real (or manufactured) personal lives. Attending their favorite actor's movies gave viewers a sense of being personal friends with their idols, made more real by their gigantic appearance on the silver screen.

Soon independent filmmakers dominated all phases of the industry. Out of this group emerged the Big Five: Fox, MGM, Paramount—and, later, with the coming of the 'talkies,' RKO and Warner Brothers. These giants learned how to attract the widest audience, and to appeal to those customers' longings, fears, and values. The Big Five controlled the huge American market, and thus benefited from lower fixed production and distribution costs than was the case in smaller countries. This made it easy for them to penetrate foreign entertainment markets. By 1918, the United States produced 85 percent of the films shown worldwide. The appeal of the romantic and fast-paced American movies assured their dominance in the production of popular culture, a position that continues to the present.

After 1909, moviemakers began to move production from the New York area to Hollywood, California to take advantage of its sunshine, geographical diversity, and cheap labor. This migration did not necessarily affect the content of films, because most producers had their roots in the urban immigrant communities of New York and Chicago, and their productions continued to reflect the tastes of Eastern moviegoers. By 1915, the silent film industry had become a mixture of the popular culture of immigrant movie-lovers and the high-mindedness of the American middle class.

It was only when sight and sound were synchronized that movies came to dominate American culture. The popularity of the movies increased sharply: Weekly ticket sales rose almost 55 percent between 1926 and 1929. Old stars with thick European accents or squawky voices who displayed exaggerated gestures in silent films gave way to actors with 'natural' voices and more 'intimate' styles. Legions of local piano players who had developed the art of complementing the images on the screen with music were thrown out of work. That talent was transferred to the Hollywood sound stage. Music then shaped the film in many ways: Singing cowboy movies of Roy Rogers and Gene Autry appeared, along with the extravagant song-and-dance films of Busby Berkeley. During the silent era, moviegoers could talk and even 'talk back' to the screen. But with sound, audiences insisted on silence in front of the screen, so that the screen could speak. Viewing became a much more solitary activity. Clearly, the most popular form of public entertainment in the 1920s and 1930s was the film. As early as 1930, 100 million tickets were sold weekly. Attendance peaked in 1946 when three-quarters of those who could attend movies did so each week. For the young, moviegoing was a ritual enjoyed eight or more times per month. The movies produced a mass culture. They were as different from the elite culture of the book and live performance as they were from the traditional 'folk' culture of the neighborhood. Movies were shared across class and region.

The movies created a new kind of relationship between audience and performer in the celebrity 'star.' For the viewer, that person had to be elevated to the heavens, but also be seen as a friend, an equal to be identified with. Anyone, in theory, could be a movie star, even though few made it to the top. The star rose (and often fell) with previously unheard-of speed.

Though movie makers touched the lives of most Americans, film producers could not do as they please. In the early Depression, film studios tried to win audiences with movies that featured mild violence and sexual themes. However, pressure from religious groups concerned especially about the impact of these films on children forced movie makers to enforce the Production Code from 1934 that banned graphic violence and overt sexuality. This did not mean that American films generally were made to uplift or indoctrinate viewers. The commercial character of the American movies assured that motion picture technology was used to entertain with comedy, adventure, and romance.

Films, more subtly, transformed entertainment. A story from a book (or real life) that might take hours (or years) was compressed in the story-telling of the movies. The visual effect of close-ups on a projected screen and rapid cutting of scenes, especially with the added impact of amplified sound, assaulted the senses. Over time, viewers often found the extreme to be normal and expected more thrills. In the long run, movies tended to favor action over character development and even plot, as witnessed by the pyrotechnics of modern horror and action hero movies.

With the advent of television, the reign of the Hollywood motion picture declined rapidly after 1946 when its audience peaked. By 1953, when almost half of American households owned a television, movie audiences had shrunk by half. The movie business responded by offering what the black-and-white TV screen could not provide: Three-dimensional movies (1951), extravaganzas in widescreen CinemaScope (1953), and films directed toward the young and in love (who wanted entertainment away from the eyes of mom and dad). Exhibitors also appealed to families (and young couples) with the drive-in theater, which had its heyday in the 1950s. In the 1960s, X-rated features took over some old movie whouses. In 1968, the modern rating system replaced the old restrictive Production Code of the 1930s, winning crowds from the bland fare of TV with sex, violence, and profanity in 'R' rated films while providing family-friendly films rated G,' with the intermediate 'PG' added in 1970 and the 'PG-13' rating in 1984. With the rating system, especially PG-13 there was an increase in violent and suggestive films. And from the 1970s action-adventure films became more graphic and plots became more abbreviated with movies like Clint Eastwood in *Dirty Harry* and Sylvester Stallone in *Rambo* as Hollywood strived to reach young (often male) audiences. Limited dialog also facilitated the selling of American films across the globe.

While none of these innovations reversed the downward trend in movie-going, the motion picture camera and other technologies that produced this mass-distributed visual entertainment largely displaced live theater and other forms of story-telling (including the book). Along with the primarily personal technologies of the phonograph and snapshot camera, film transformed how we and hear. This may be even more true with radio and television, our next topic.

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17 Electronic Media in the Home

In 1900, Americans were amazed to hear sound from a grooved disc and see moving images from a roll of celluloid even as they soon grew accustomed to experiencing audio entertainment in the home on the phonograph and video on the screen of the movie theater. Entertainment had once been found in listening to or joining local groups of people singing and playing instruments and viewing live plays at special times. These communal pleasures were gradually replaced by something new: Those entertainments were transformed into a largely private experience of listening to recorded music at home and viewing movies in a silent crowd at the theater. Yet, these experiences were often shared by millions across the nation and even globe. Compared to the old entertainment it was passive but allowed for far more choice in both what and when it was experienced.

As revolutionary as all this was, it was only the beginning of a fundamental transformation of media and entertainment. An even more magical set of technological innovations based on electronics made phonographs and films seem almost primitive: Early in the twentieth century, inventors had found ways to transmit voice and music without wires or records. In the 1920s, the companies that gained control of this technology broadcast audio into the homes of everyday people with simple receivers called radios. By the late 1930s, labs that were mostly linked to the radio industry took another step by transmitting both moving image and sound wirelessly to televisions parked in living rooms where radios once stood. Even more than the phonograph and the movie, radio and television domesticated entertainment while simultaneously expanding a common mass culture.

This meant fewer people made the intermittent visit to the neighborhood café to hear a community talent or gathered at a nearby baseball field to see a town team play. Instead, people heard national celebrities perform every Wednesday night at eight on the radio and millions watched the same situation comedy at nine pm on Thursdays in the privacy of the home. Gradually, the phonograph and movie were displaced by the 'free' but in America heavily commercialized broadcast media of radio and TV. But, by the 1980s, the mass culture of broadcasting technology was giving way to the narrowcasting of cable and satellite TV and by new electronic devices like the VCR and later streaming technology that allowed new ways of choosing what and when to experience the wider world individually. The privatized but shared mass culture of the twentieth century has become the personalized and fragmented, but globally tapped, culture of the present.

The Development of Radio

Unlike so many of the technologies we have considered, radio was the offshoot of a purely scientific endeavor. Physicists had long inquired into the relationship between magnetism and electricity. There was no scientific awareness of electromagnetic waves until James Clerk Maxwell theorized their existence in the 1860s. When Maxwell and Heinrich Hertz experimented with producing and stabilizing electromagnetic waves in the 1880s, they were interested only in understanding nature. Hertz himself asserted that commercial radio was impossible. Oliver Lodge demonstrated such a 'wireless' device as a scientific curiosity in 1894 with a spark gap transmitter, an open-ended loop of wire across which a spark radiated (thus radio) electromagnetic waves, which, in turn, were detected by a receiving device.

However, quickly a number of inventors, among them the Italian, Guglielmo Marconi, began to look into the practical possibilities of using these mysterious electromagnetic waves as a substitute for the electric telegraph and even telephone wires. Marconi was not interested in using this discovery for mass entertainment; the market that Marconi aimed for was ship-to-shore communication—messages beyond the reach of the wire. Radio communication over water promised to reduce loss of ships at sea. had obvious advantages to navies and global commerce, and simply provided competition to wired telegraph companies (Figure 17.1).

Once the science was understood, the idea of radio was fairly simple. Electric current emits electromagnetic waves. These in turn will influence electrical devices. The trick was to make transmitters powerful enough and receivers sensitive enough that coherent messages could be transmitted. Lodge's spark transmitter was not powerful enough to do more than generate intermittent signals in Morse Code, but these could be picked up by distant receivers. Marconi borrowed several key ideas from telegraphy: Grounding both transmitter and receiver, using a relay device to augment current in the receiver, and using the telegraph key to transmit Morse Code. In 1901, with the help of the scientist John Fleming, Marconi successfully transmitted across the Atlantic, from Wales to Newfoundland.

Some visionaries saw a potential role for wireless as more than a substitute for the telegraph and turned their attention to the possibility of a wireless telephone based on continuous transmission that, when modulated (like the telephone), could relay voice messages without wires. A key invention was the alternator, developed by the English Reginald Fessenden at GE, which turned

Figure 17.1 Guglielmo Marconi with his wireless telegraph. Notice the tape containing the code.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

direct current into alternating current, producing continuous radio waves as a byproduct, which, by 1906, succeeded in transmitting voice. But Fessenden's alternator could not overcome problems of excessive power usage and frequent breakdown.

Another path toward wireless voice communication was the vacuum tube. Scientists had been curious for decades about the 'Edison effect,' the pattern of discoloration observed in light bulbs. Edison himself had experimented with the insertion of a second electrode in the light bulb to eliminate this discoloration. It turned out that the addition of this second electrode opened up new possibilities totally unconnected to the light bulb. John Fleming, in England, was the first to notice that electrons moved only from the hot to the cold electrode. This led to the electronic valve. Because currents would flow in only one direction, the alternating current of electromagnetic waves could be translated into the direct current needed to generate sound waves in the receiver. The original vacuum tube looked much like a lightbulb.

An American innovator and entrepreneur named Lee De Forest constructed a vacuum tube that essentially copied Fleming's diode (i.e. two-electrode tube), without admitting his debt. However, De Forest added a third electrode in the form of a grid in 1906, that critically amplified the flow of electrons between the other two, a heated filament and plate. De Forest did not understand the science of electrons and believed mistakenly that it was ionized gases that passed between electrodes. In any case, this dramatically improved the reception and transmission of radio waves. The purchase of De Forest's triode by Bell (ATT), initially to amplify long-distance telephone signals, led to the corporate dominance of further development of radio technology. The key players were ATT, GE, and Westinghouse (who bought patent rights to an improved audion invented by Edwin Armstrong) (Figure 17.2).

World War I accelerated technical development and corporate consolidation of control over radio. Those years between 1914 and 1918 saw greatly increased production of both receivers and transmitters. Because of the frustration of the United States Navy, which had to deal with the remaining British Marconi patents during the war, the American government encouraged GE to purchase American Marconi forming RCA (the Radio Corporation of America). Soon ATT and Westinghouse joined RCA as minor stockholders. These companies then pooled their various radio patents. While the goal was to gain American dominance over transoceanic wireless communications for 'national security' purposes, this patent pool guaranteed that, in the long term, a few interlocking commercial corporations would dominate radio development in the US.

Soon the possibilities of marketing radios for home use became obvious to these corporations. As early as 1916, David Sarnoff, future chief of RCA and NBC, recognized that the radio, unlike the 'wired' telephone, could not confine messages to private individuals; thus, corporations could not easily charge for these communications. Sarnoff realized that the radio was more like the phonograph than the telephone: The radio could bring into the home a form of entertainment that otherwise was available only in public performance or on expensive records. The radio followed the path of its predecessor, the phonograph that began as a device to record private messages, but was transformed into a machine of commercial entertainment.

Still, the big companies were slow to recognize the potential for mass entertainment. Amateurs had to show the way. From the beginning of radio, amateur radio 'buffs' communicated with each other via homemade 'crystal' receivers (anticipating 'solid state' transistors) and primitive transmitters. During the 1910s, amateur broadcasters produced broadcasts of music and talk to other like-minded radio enthusiasts from five-watt transmitters set up in bedrooms or chicken coops. In 1920, Westinghouse recognized that broadcasting was a way of selling personal radios. The result was KDKA, a hundred-watt Pittsburgh station that Westinghouse first built in a rooftop shack. Others quickly joined in, offering sports, religious, and news programs that reached a million Americans by 1923.

Drawing on their patent pool with RCA, GE and Westinghouse began to concentrate their commercial efforts on home radios, while AT&T (leaving RCA) built transmitters for radio stations. Amateurs, some of whom became

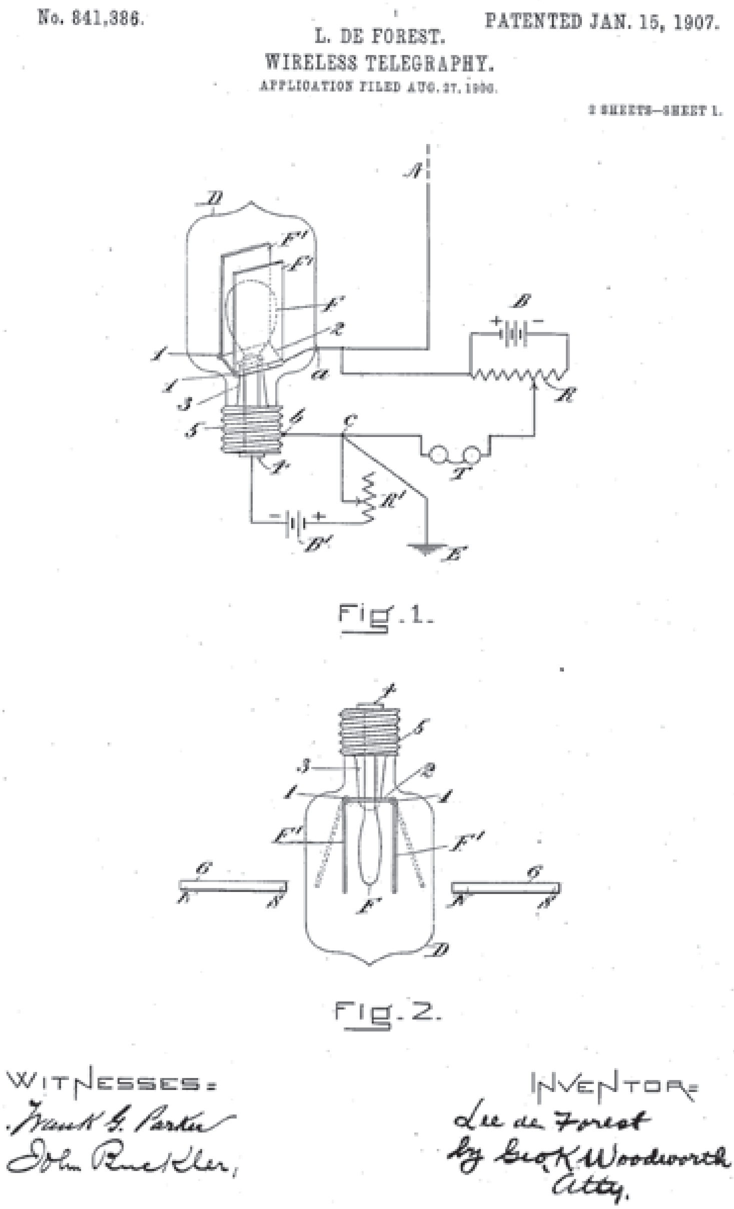

Figure 17.2 The DeForest vacuum tube as described in his patent application, 1906. Both amplifying and rectifying AC radio waves into a direct signal that could be converted to sound, it was vital for long distance telephones and radio.

Credit: *Courtesy of the US Patent and Trademark Office.*

manufacturers, easily circumvented this would-be monopoly. By 1922, there were 600 stations on the air, mostly independent of the big corporations in the patent pool. Public pressure forced RCA to license other firms to produce receivers; these companies would be responsible for a host of technical improvements. RCA would soon find another way of dominating radio, by developing a network of stations.

American Radio Culture: A Commercialized Entertainment Technology

While radio began as a wireless telegraph and telephone, it soon became a mass-media technology based on a network of transmitters controlled by major corporations and cheaply manufactured home receivers. The problem was how to pay for—and profit from—broadcasting information and entertainment to scattered individual listeners. The owners of transmitters had no way of charging for home reception. While other countries developed various types of publicly financed broadcasting (annual licenses, for example), Americans created a small group of competing networks that funded programming through advertising.

When serious broadcasting began in 1920 in the United States, most local stations relied upon recorded music and volunteer performances, which individuals offered for publicity and the sheer novelty of being on radio. By 1923, though, recording artists began suing for copyright infringement. Moreover, the initial boom in radio sales dropped, making manufacturers less willing to subsidize broadcasting. New sources of income had to be found. At first David Sarnoff at RCA called for government subsidies or license fees (to be paid by radio receiver owners) to be used to fund broadcasting. But in the United States in the 1920s, when laissez-faire capitalism reigned supreme, these proposals smacked of socialism.

In 1922, an AT&T-run station in New York found another solution more compatible with the American climate: It ran a ten-minute advertisement for a Long Island real estate developer. The next year, AT&T linked a number of local stations (with its long-distance telephone lines) into a small 'network' of stations. This move both spread the costs of programming over a larger audience and offered advertisers a bigger market than any local station could provide.

AT&T's threat to create a network monopoly frightened RCA, Westinghouse, GE, and others who were excluded from the AT&T network. When AT&T announced plans to market radio receivers in 1923, these companies feared that the telephone giant was on the verge of creating a monopoly. After threats of lawsuits, a compromise was reached in 1926: AT&T sold its stations, while RCA, GE, and Westinghouse formed a new network, the National Broadcasting Corporation (NBC) that would lease AT&T long-distance lines. Within a year NBC, with its Red and Blue networks located in New York

City and New Jersey, was competing with the Columbia Broadcasting System (CBS), created by independent radio stations.

It was only in 1927, after the commercial network system was firmly established, that the Federal Radio Commission was founded. Its role was only to assign frequencies, not to control radio programming or to establish public service radio. Court orders forced GE and Westinghouse out of RCA-NBC in 1931. In 1943, in a suit filed against NBC for violation of antimonopoly laws, a court forced NBC to sell the 'Blue' network, which eventually became ABC. Still, the close linkage between these powerful companies would assure a highly centralized radio (and later television) industry.

In other countries, broadcasting went in other directions. Radio and later television remained public, becoming a vehicle of political propaganda and/or cultural uplift. For example, in 1922 a group of British radio manufacturers sponsored a central broadcasting facility for all of Britain. But in 1926 it became a semi-autonomous public broadcaster (the British Broadcasting Corporation, or BBC), whose government-sanctioned monopoly was funded by obligatory radio licenses sold through post offices. The BBC attempted to improve national culture with a mixture of educational and family entertainment programming.

By contrast, the commercial character of American radio made broadcasting a tool of national advertisers and an expression of mass culture. In its first two years, NBC programming imitated the BBC model with 'serious' classical and sedate dance music. But, in the 1928–1929 season, the first situation comedy, adventure, and variety shows appeared. The competitive nature of the network system encouraged programmers (often the advertising agencies themselves) to deliver large shares of the mass market to sponsors. This produced mass entertainment, rather than efforts to cultivate specialized interests or tastes.

Like the movies, radio at first borrowed heavily from traditional media: Vaudeville singers and comedians like Eddie Cantor and Jack Benny had their own radio shows. This led to the final demise of live variety theater. Soon programming began to reflect the peculiar power of radio technology: The advantage of the immediacy of live media (as opposed to the phonograph or movie) was exploited in special-events broadcasting. Especially popular were radio broadcasts of sporting events, political conventions, and even media stories like Charles Lindbergh's famous transatlantic flight of 1927. News reports were short and featured the voice and particular manner of the announcer. Radio stars were also shaped by the technology. Singing voices became softer, first to spare sensitive microphones and then to adapt to the intimacy required by listeners gathered in living rooms. The mellow crooning style of Bing Crosby, first heard in 1929, became a standard. The variety show of music and comedy was especially well adapted to radio. And local radio stations even hired their own bands or broadcast live from local dance halls. Overall, though, radio likely limited the job opportunities of local musicians.

Radio produced the peculiar American art of the soap opera, dramatic stories (sponsored by soap and similar sponsors) directed toward homemakers that were aired in 15-minute segments each weekday afternoon. For many stay-at-home women, hearing the miseries of their radio 'neighbors' made their own problems seem more manageable during the Depression years. The situation comedy or 'sitcom' was also popular. In the early 1930s, two-thirds of the radio audience listened to *Amos 'n' Andy*, a comedy that reinforced racist stereotypes of mostly incompetent black males (though its lead roles were actually played by two white men). Western, mystery, and children's adventure programs were taken directly from comic books and other cheap 'pulp' magazines. *The Cisco Kid* (a western) and *Superman* were only a few of the radio shows that later would move to television. What worked on radio one year was widely imitated by others the next. This trend was increased by the introduction of listener surveys in 1935. This was the beginning of the modern rating system.

At the core of American radio, of course, was the commercial. In effect, the networks sold a mass audience to advertisers of brand-name products (especially cars, cosmetics, cigarettes, and soft drinks). Advertisers took advantage of the ratings to reach the largest audience for their products. If all of this sounds familiar, it should: Most of the basic patterns that we associate with television were in place in the radio era.

The radio was probably the most important new domestic consumer good in the interwar years. In the early 1930s, dramatically lower prices brought the radio into most American homes. In 1932, there were about 17 million American households equipped with radios. A survey in 1938 found that 40 percent of American households on a typical winter evening had the radio on. Since evening schedules mixed programs designed for different ages and sexes, families were encouraged to listen together. The radio was the new family hearth, and often was designed to look like one.

The radio was surely more important to Americans in the 1930s and 1940s than the movies. After purchase, its content was free. People, who in the Depression could no longer afford the movies, could still hear their stars on the radio. Though having to endure ever increasing numbers of ads (often played at volumes louder than shows), Americans heard recording artists and swing bands without having to buy expensive records. This cut into the sales of the phonograph, even as the phonograph was improved with radio tube amplification and electric microphone recording and loudspeaker playback. At the same time, however, the cost of radios declined in the 1930s (up to 90 percent) with cheap table top models (Figure 17.3).

But the shift to radio entertainment was about more than costs. Unlike the motion picture, listeners did not have to leave the house, go to a potentially dangerous part of town, sit next to strangers, or buy a ticket. Instead, radio listeners could remain safe with their families, turn the radio on or off, and change the volume or station at will. They could even listen while working or in bed. The radio was (and remains) well adapted to household

Figure 17.3 Even the most remote communities were exposed to national popular culture by the radio.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

activities. Radio relieved the isolation of women in homes during a period when the number of relatives and children in the house all day was declining. Most of all, the radio wonderfully reconciled two things most Americans wanted: Privacy and a community of shared information and entertainment, thus reinforcing a trend that began with the phonograph and would continue with television.

The legacy of radio is complex. Limited competition among the national networks in the United States led to programming that was designed to deliver the largest market share to advertisers. Despite appearances, few historians believe that this simply created a mass culture. The radio may well have helped to link ethnic groups who listened to the same local radio programs. But, even on the networks, there was diversity of programming and not all of it was 'lowbrow' sitcoms and soap operas. In the 1930s, NBC aired classical music concerts on Thursday evenings, introducing 'serious' music to millions. At the same time, radio led to the sharp decline of singing at home around the piano, and conversation was disrupted by the call of the *Paul Whitman's Kraft Music Hall* or the latest episode of *Flash Gordon.* The radio did not lead to mere passive private entertainment. It required an imagination (not demanded in the same measure by movies or, later, television) in translating mood music and sound effects into a New York street scene or an Alaskan forest. Radio was a unique combination of popular, commercial, and even edifying entertainments.

Like the movies, radio changed after 1950 when major sponsors shifted to TV. The last radio soaps went off the air in 1960. Despite the obvious superiority of TV for entertainment, the lasting advantage of radio over television was that radio could be mobile. In the 1950s, the car radio became almost standard, and cheap transistor radios appeared. As a result, radio became a favored media of the freeway-bound and the young. It became a major source of news and, by its constant presence, eased people through the day. Just as network radio was losing its programs to TV, recorded rock music appeared in 1953 to fill the vacuum (and to provide a vehicle for youth-oriented advertising). These recordings were quickly heard on radio. Disc jockeys like Alan Freed and Wolfman Jack identified with the youthful listener and were closely associated with rock. Radio has not only survived but blossomed. In fact, the number of stations grew from 973 in 1945, the heyday of network radio, to 9049 by 1981.

Radio also belatedly became a bastion for cultural diversity especially from the 1970s when the potential of FM radio began to be realized. Although FM was patented in 1933 by Edwin Armstrong, the hostility of AM-based networks and manufacturers (especially RCA) blocked its early success. Only when FM stations began broadcasting in stereo in 1961 did it spread—at first, to demanding listeners of classical and specialty music. After 1971, when National Public Radio began broadcasting, FM facilitated also the growth of educational stations. AM stations survived and became the home of 'talk radio.' By the 1980s, the mass audiences that early radio had attracted were segmented into small, but loyal, groups drawn to a particular format (soft rock, oldies, country, religion, jazz, classical, or news and talk). Also in the 1980s and 1990s, government deregulation allowed stations to air more commercials, and encouraged big corporations to purchase local stations—creating efficiencies in broadcasting, but also reducing local content and diversity.

Television

Like radio, the origins of television can also be traced to science. It began with the discovery in 1883 that the electrical resistance of selenium varied with light. Paul Nipkow experimented with a spinning disc with spiral holes to capture an image point by point in a series of lines on a selenium cell. These points of light could be electronically transmitted to a receiver that reversed the process, in theory, creating an identical image. The slow reaction of selenium to light and the inefficiency of the Nipkow disc limited the quality of the transmitted image, not to mention moving pictures. Finding an alternative to the mechanical disc to scan the image began in 1897, when the German-born Karl Braun invented the cathode-ray tube (CRT), whose electron beam rapidly fired electronic signals at the interior phosphorescent surface of this vacuum tube producing an image seen outside the tube. At first the CRT was used mostly to display electronic signals as waves for science; but later, when improved, it was used as a television picture tube to display a transmitted image line by line electronically. While the electron beam eventually solved the problem of the Nipkow disc, an answer to the slowly reacting selenium was found in the photoelectric cell (1905). This device translated light into electronic signals much faster than selenium and made possible the transmission of still photographs and texts (a primitive facsimile machine emerged shortly after World War I). However, these early electronic devices were inadequate to capture and scan moving images for broadcast television or to produce a TV receiver that could reverse the process. In fact, TV innovators like John Baird of Britain kept trying to build a workable system based on the mechanical disc into the 1930s without much success; he never got more than 240 lines of image on a screen (less than half of the standard established in the 1940s).

The problem was that a television camera must scan a picture in small blocks, usually from left to right in a series of lines. And this must happen very fast for moving pictures not to jump and be fuzzy. In 1931 it was estimated that seven million picture elements per second would have to be transmitted for good picture quality. At the time, researchers were struggling to achieve four thousand. A revolution in scanning techniques required improved electronics (Figure 17.4).

Television with fully electronic scanning was to be a product of the industrial research labs of the major American corporations. And most of this development was undertaken by companies with radio interests, RCA/NBC, CBS, and ATT. These companies wanted to dominate the next media technology, correcting the failure of Western Union's telegraph empire to control the telephone in the 1870s. Important additional development was made by solitary inventor, Philo Farnsworth who invented an early electronic TV system and Allan DuMont, who in the 1950s led a short-lived TV network.

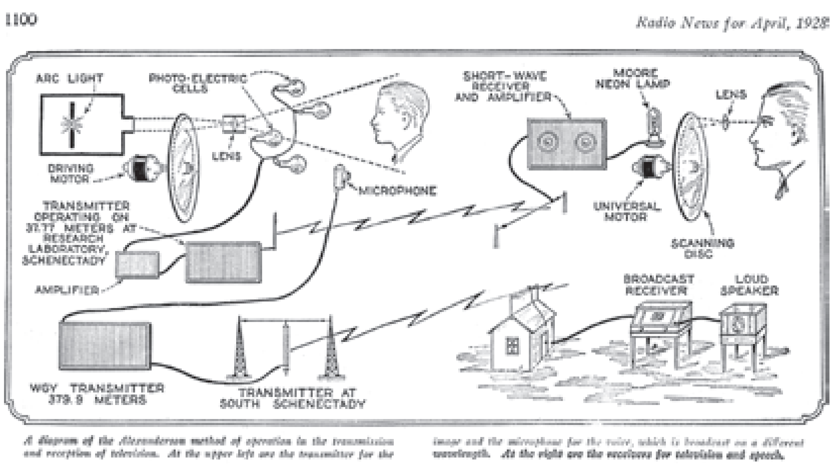

Figure 17.4 A schematic image of a mechanical TV system using scanning discs.

Credit: *Wikimedia Commons, first published in* Radio News, *April 1928, copyright not renewed.*

However, even though TV research began before the founding of the radio networks in 1926 and 1927, it was slow going. Russian-born Vladimir Zworykin had filed a patent for electronic television camera in 1923, but the pictures he could obtain at that time were so poor that his employers at Westinghouse chose not to pursue the project. Seven years later, Zworykin became the head of RCA's lab that gave him more resources for TV development. But research was slowed by the Depression. Zworykin and his team at RCA were challenged by Philo Farnsworth, whose system could transmit only very bright pictures but incorporated elements of a superior scanning system. By the late 1930s, RCA and Farnsworth locked horns in a series of patent suits that led to an understanding that each held important patent positions, and successful television depended on cross-licensing. They finally reached such an agreement in 1939. FM audio was adopted for TV in 1941, though, as we have seen, its use for radio was delayed by AM radio interests.

The next hurdle was government regulation. While the BBC introduced television service in 1936 and NBC followed at the New York World's Fair in 1939, the product had to be standardized for national adoption. The Federal Communications Commission in 1941 settled on the 525–line-screen, 30–frames-per-second, and 6–megahertz bandwidth standards used throughout the twentieth century. However, World War II naturally delayed the spread of TV. Televisions could be found only in eight-thousand American homes in 1946, but that number rose to one million by 1949, ten million by 1951, and forty-five million—90 percent of all homes—by 1960.

Early television added images to the audio channel of radio. Transmitted over radio signals from local stations to home antenna and tube-based TV sets, reception was largely limited to the three networks that began in radio and programming and was in black and white. TVs were thick (especially to accommodate the picture tube with its electronic gun at the back and the bed of other tubes). Viewers used controls on the set and often had to adjust the 'rabbit ears' antenna on top of the set to receive a clear image without 'snow' interference. By the 1960s, the transistor (Chapter 20) replaced costly tubes (except the one for the picture) that formerly had often burned out. The remote control began with an ultrasound device in the 1950s, but improved by the mid-1970s with infrared systems that became standard by the 1980s on most new TV sets. As with the introduction of color to films, the story of the colorization of TV is complex. Experiments with it began as early as 1941, but commercial adoption was delayed by costs. The first color TV sets appeared in 1953, but the high price and lack of color programming by the networks kept sales at a trickle. Only in the mid-1960s was price and programming sufficient to convince consumers to switch from black and white sets.

In 1974, the video cassette recorder or VCR was introduced. This tape machine allowed viewers to copy TV programs for later watching or to play recordings of movies on home TVs. However, the analog VCR was largely replaced by the digital video device (DVD) soon after it was introduced by

Japanese manufacturers in 1996. DVDs have in turn been displaced by digital video streaming from the internet (for digital technology, see Chapter 20).

While cable TV was available from the late 1940s, especially where over-the-air reception was poor, broadcast TV was cheap, and the Federal Communications Commission placed limits on cable in the 1960s at the request of broadcasters. However, restrictions were gradually lifted after 1972 and satellite technology made possible the transmission of distant signals. Then cable networks proliferated delivering new programming into homes by wire. The first cable network was Home Box Office (1972). Ted Turner followed in 1976 when he uplinked his TV station in Atlanta to a satellite transmitting it eventually to a national network of cable systems.

Other innovations changed the look of TV. The protruding CRT that gave TV its bulk and weight gradually gave way to a series of flat-screen TVs. The first, invented in 1964, was plasma TV with images appearing from the light emitted by charging neon and xenon gases. Plasma is expensive and this flat-screen technology has gradually been replaced by Liquid Crystal Display (LCD) TVs. LCD TV use pixels formed by two layers of polarized glass filters (subdivided into subpixels of the primary colors). Between these glass filters is a thin layer of liquid crystal that can be switched on or off (twisted or untwisted) electronically. This opens or closes the emission of light from cold cathode fluorescent lamps or CCFL at the back of the screen, creating the illusion of color images through the glass filters. This technology was followed by Light Emitting Diode (LED) TVs where the CCFLs are replaced by semiconductor material (LEDs) emitting patterned light that subsequently are viewed through LCD screens.

Though these technologies had roots in the 1960s and before, they became commercially viable for TV only around 1996 when Sony and Sharp pooled their technology to market plasma TVs. By 2006, the semiconductors used in LEDs were improved to compete, gradually leading to the eclipse of plasma and LCD. These flat panel displays produced not only higher resolutions but allowed for much larger screens. By 2009, giants like the 160 by 72-foot LED screen that straddles the stadium of the Dallas Cowboy football team allowed fans in the stands to see replays of exciting (or controversial) action. Finally, in 2009, TV signals began to switch from the old analog to a digital format greatly improving picture quality. Shortly after, digital TV was linked to the computer internet (Chapter 20) with applications like YouTube and Netflix for video streaming from wireless modems. All these innovations since the arrival of the black and white tube TV in the early 1950s transformed viewing in many and subtle ways.

TV and the Origins of Primetime Families

As we have seen, TV was developed largely by the same companies as radio; and for decades it was dominated by the three broadcast networks that began in radio (NBC, CBS, and ABC). TV quickly came to dominate popular culture, just as radio had before World War II. By 1954, there were already TVs in 55 percent of American homes, just nine years after the war (a percentage that took 37 years for radio to reach). By 1967, American homes consumed an average of five hours of television per day. Like the radio, commercialized TV delivered the mass market to national advertisers.

Indeed, program formats and even specific shows were adapted directly from radio. American television copied the radio's uniform program length, punctuated by advertisements. It embraced radio's division of daily programming into morning talk and game shows, afternoon soaps, late afternoon children's programs, and evening primetime. Shows as varied as *GE Theater, Dragnet* (police), *Burns and Allen* (sit-com), *The Ed Sullivan Show* (variety), and *Meet the Press* (news) were taken from radio as were the familiar formats of sitcoms, westerns, and detective shows.

The linkage with the motion picture was also strong. Although early TV, like the early movie and radio business, was centered in New York City, after 1951 television migrated to the movie studios' sound stages of Hollywood. The flexibility of film over live telecasts was obvious. 'Bloopers' and timing problems could be corrected in film editing. In 1951, Lucille Ball and Desi Arnez began the trend when they produced their first *I Love Lucy* sit-com episode in Hollywood. Motion picture companies formed television offshoots (e.g. Columbia's Screen Gems). The upstart network, ABC, sought to improve its audience share by hiring Warner Brothers, a major moviemaker, to film the western series *Cheyenne* in 1955. This collaboration was followed by many imitations: By 1959, 32 westerns literally saturated the airwaves. The coming of ABC's *The Untouchables* in 1960 set off a similar rush toward police 'action' shows. Television's advantage of combining radio's privacy and immediacy with the movie's visual imagery encouraged fast-paced action programming.

Despite these roots in popular radio and movie entertainment, early TV promoters dreamed that this new device would raise American cultural standards by introducing the arts, educational documentaries, and especially live and topical programming to American living rooms. To be sure, TV in the 1950s provided airtime to critically acclaimed drama such as *Kraft Television Theater*, intellectually sophisticated quiz shows like *What's My Line*, and news programs such as Edward R. Murrow's *See It Now*. But there were also vaudeville-influenced shows like Milton Berle's physical comedy from 1947 to 1956 and Ed Sullivan's variety show on Sundays from 1948 to 1971.

The early commercial networks also offered public interest programming on Sunday afternoons (*Omnibus*, for example, which was rather like the later public TV program, *Nova*). But advertisers lost interest in 'prestige' drama and documentaries by the late 1950s. In part this was because by then nearly everyone had a TV, which attracted advertisers to more popular programming that promised high ratings. Network educational programming on Sundays gave way in 1964 to broadcasts of National Football League games, which could sell millions of viewers to Budweiser and General Motors.

However, the change in programming was about more than a shift toward a mass-audience attractive to advertisers of mass-market goods. New programming was an unexpected effect of the character of TV viewing and technology. Unexpectedly, TV became not an opportunity to share the new and unique, but a media that featured the repetition of the familiar and conventional. In the beginning, shows were live (mostly from New York City), distributed across a wired network that linked local broadcast stations, which, in turn, beamed this live programming to the antennas that reached into American homes. As late as 1955, 87 percent of network shows were still live in the evening with primetime filled with musical variety and dramatic programming. Audiences enjoyed the mystique about the immediacy of live shows and the networks profited from selling primetime slots to advertisers eager for national audiences.

Challenging this vision was the idea of recorded and thus repeatable programming that by the 1960s dominated TV. Local stations without resources for live shows needed such programs, especially in the non-primetime viewing hours, when early networks had few programs. Moreover, live shows at eight p.m. from the East coast had to be seen at five in California, creating an economic incentive to record these shows for evening viewing. An early solution was broadcasting old movies and cartoons that film makers readily sold to local TV stations for the 'late show' or afternoon movie slot. This introduced a new generation to the films of Hollywood from the 1930s and 1940s. Moreover, a large number of TV serials were produced by non-network telefilm companies for syndication to local TV stations. Drawing on a practice introduced in the 1930s on radio (which played transcriptions, i.e. phonograph recordings of live programs for later listening), TV programs were recorded on kinescope, films taken from cameras in front of a television monitor of the live New York show that was played later in western time zones. A much improved technique came with videotaping in 1956.

These recorded programs made the rerun possible, beginning in 1955: Local stations ran 'strips' on weekday afternoons of old sitcoms or westerns that were first shown once a week in primetime. Beginning in 1958, the networks broadcast reruns of shows aired during the 39-week season during the summer when ratings dropped. Many people enjoyed seeing the shows again. TV didn't have to be live.

Over time, the TV serials changed (from the family sitcoms of the 1950s like *Leave it to Beaver* to the 'buddy' sitcoms featuring same-age characters like *Mary Tyler Moore* and her news team in the 1970s or *Cheers* with its bar flies in the 1980s, or *The Big Bang Theory* with its comical nerds in the 2010s. Many sitcoms made it into reruns and were watched decades after they were first broadcast to nostalgic audiences seeking to capture memories of their youth in front of the TV set. They also attracted new audiences, curious about the tastes, humor, and values of the past.

Not only did reruns become a dominant form of TV programming, but the shows themselves became highly predictable. Sitcoms, for example, depended on a few well-defined and never changing characters, and simple, largely domestic or other group, settings (as in the suburban living room). But what animates the episodes are the 'situations,' consisting of a 'crisis,' and ultimate resolution of the problem within 23 minutes. The predictability of these shows has been and still is comforting and oddly empowering. The fact that viewers know what will happen next makes them feel part of the show. Other TV genres shared this comforting predictability (westerns, police-procedurals, etc.).

Television programming seldom strayed far from the dominant culture of its time as the three networks competed for the same broad middle-class audience. For example, television became nearly a perfect expression of the suburban life in the 1950s and 1960s. It celebrated domesticity in the sitcoms and warned of urban dangers in action-adventure shows, while enticing viewers through commercials to suburban fast-food chains and shopping malls. TV reinforced the trend (established by radio) of homebound privacy: It is no surprise that the TV dinner, eaten from a tray in front of the 'box,' appeared in 1954.

Further innovations transformed television, and eventually reduced the power of the big three networks, ultimately segmenting the viewing audience: These changes included multiple TV sets per household, cable TV, and alternatives to conventional TV. Solid state technology that replaced tubes allowed for cheaper and easily portable TVs. No longer was the console TV set in the living room (usually controlled by Dad) the only set in the house. From the 1960s, additional sets were placed in basement family rooms or even in children's bedrooms, breaking up family viewing and creating the possibility of programming designed for narrow age, gender, and taste groups. While in 1975 already 43 percent of American homes contained two or more sets, by 2010 that proportion had risen to 83 percent with 28 percent containing three or more sets—and at a time when more Americans were living alone and without children. The coming of color television by 1965 increased viewing by as much as 20 percent. New technologies like satellite communications (1963) made global news and sports events instantaneous—a fact that affected Americans' perception of the Vietnam War, for example.

Surely one of the greatest changes came with cable in the 1980s. Cable offered not only clearer reception but many more stations (accessible 24-hours a day, rather than signing off at midnight). These features made cable attractive even if viewing was no longer free as with over-the-air broadcast TV (and most of cable TV came with ads, formerly the 'price' of cost-free over-the-air television). Early advocates of cable suggested that the expansion of access to a variety of channels would end the practice of broadcasting to the 'lowest common denominator' with bland and general programming: Cable would encourage 'narrowcasting' to more demanding and specialized audiences. A network that previously had to compete for a large share of the majority of viewers (a rational decision when there were only three major networks) now could control all of a much smaller audience. For example, in 1981, MTV tapped into a market of youth, showing rock music videos and Ted Turner introduced the Cable News Network in 1980 and Turner Classic Movies in 1994 to news junkies and old movie lovers.

At the beginning, innovative cable networks like The Learning Channel, Discovery, Arts and Entertainment, and Bravo appealed to niche and even highbrow audiences with new programming. However, cable quickly found that fresh documentaries, concerts, and plays were prohibitively expensive for the small audiences that a cable channel could draw. These and many other cable networks shifted to low-cost, often rerun shows that drew often specialized, but not elite audiences. For example, Arts and Entertainment (A & E) ran reruns of syndicated crime shows. Bravo abandoned its 'film and arts' format in the 1980s for a youth-oriented programming and 'reality TV' fashion programs like *Queer Eye for the Straight Guy* in 2003. Others specialized in evangelical religion (Christian Broadcasting and later the Family Channel), sports (the family of ESPN channels), children's shows (Nickelodeon), working women programs (WE), African-American interests (BET), young male tastes (Spike), and even nostalgic oldsters' reruns (TV Land, Antenna, and ME TV).

These narrowcast networks appealed to segments of American popular culture as opposed to the broad audiences that the old networks had long sought to attract with family-oriented sitcoms or variety music shows. These cable channels promised advertisers that their programs might reach a small, but targeted, audience, reducing the 'waste' of advertising to people who would never buy the advertised products. Thus, advertisements on Nickelodeon featured children's goods and ME TV, health products for the elderly. Cable technology made this change possible and commercial networks seeking ad revenue from companies seeking targeted audiences for their commercials made the new TV inevitable. Meanwhile, while programming remained diverse if not often 'uplifting,' the sheer number of stations hid the fact that ownership of cable stations became increasingly concentrated in a few companies (GE-NBC, Fox, Disney-ABC, Time-Warner, Viacom, and CBS), much as had TV and radio in the days of the big three broadcast networks. The result was that a handful of multimedia corporations controlled both broadcast and cable TV as well as most movie and TV archives.

Other technological and business changes also impacted television viewing. The combination of seemingly endless choice with cable and satellite TV and the availability of the remote control led to the habit of 'channel surfing' to avoid boring bits of programs and ads. In response, TV producers offered programming that was immediately alluring in hopes of stopping viewers from 'flipping channels.' One effect was the shortening of the length of screen shots (decreasing in TV ads from 3.8 to 2.3 seconds from 1978 to the early 1990s) and shorter exchanges between characters. Notice how slow the pace of sitcoms from the 1950s and 1960s is compared to those made in the twenty-first century; note too, the short, but intense, ads.

The video cassette recorder (VCR) and DVD machine further reduced attendance at movie theaters. By 1990, rentals and sales of movie cassettes accounted for more than twice the box office gross at movie theaters. These recording devices also allowed 'time shifting' programs, and 'fast forwarding'

Figure 17.5 A 2009 photo of the gigantic flat HDTV screen (160 by 72 feet) at the then Cowboys Stadium that transformed the viewing of a football game from the stands.

Credit: *Wikimedia Commons, Creative Commons license, photo by Mahanga.*

through commercials. Computer-based programming on smart TV and mobile internet-linked devices not only further weakens the old dominance of network TV but the power of cable and satellite companies.

Despite all these changes, TV still remains the most important entertainment and information medium. Since 1961, when Newton Minnow, the head of the Federal Communications Commission, declared television to be a 'vast wasteland,' critics have complained about TV. They argue that television has failed to educate Americans or uplift their culture. One reason is that radio and TV were from the beginning vehicles of advertising and entertainment. Broadcasting to the mythical 'average' American consumer (so desired by advertisers) may well have produced what critics in the 1950s called a 'Gresham's Law' in culture. Programming, according to this theory, sinks to the lowest common denominator and places a premium on immediate gratification. With cable and the multitude of channels, the sheer quantity of television programming time inevitably has affected quality. While the movie industry at its height in the 1940s was producing only about 800 films per year, television networks had to fill 168 hours per week. And in the age of cable and streaming this problem has only deepened.

The dominance of commercial programming enters into the debate about TV quality. Just as American radio at first failed to develop a public broadcasting system, American television was also slow to create noncommercial channels. In the 1950s the Ford Foundation and some colleges established educational stations. Ironically the nearly complete abandonment of 'highbrow' programming on the networks coincided with the emergence of the Public Broadcasting System (PBS) in 1967. However, unlike the BBC, PBS was not a producer of programs—it was merely a distribution network whose programs were created by independent, affiliated public TV stations. Always underfunded and forced to rely on BBC hand-me-downs, American public television has played a small role in American cultural life (with the big exception of children's television).

Many critics blame the commercial dominance of American TV for the disappointing role the media has played in educating and uplifting the public. Others argue that the boob tube itself, and its technological capacities, are to blame. TV does not adapt well to an appreciation of continuities with the past or future (as the sensationalism of cable news shows), or to analysis of complex issues. Its small screen, placed in a private domestic setting, has created an illusion of intimacy, seen in both the cult of celebrity in talk shows and in the comforting familiarity of sitcoms. Like radio, TV has become an omnipresent 'friend' to the isolated or lonely, often always turned on. Educational and disturbing themes are usually not expected on the little screen (though this has changed somewhat with the large flat screen TVs). People turn it off, critics claim. Yet viewers use TV and understand its programming in very different ways that reflect age, ethnicity, gender, and education. And there are signs that TV is losing its grip on the imagination and time of Americans, especially the young.

Still, no one can deny the role of TV in American life. Like other audio and visual technologies, TV and our use of it fit into the American culture even as it has helped to change that culture. Television reflects a commercial society, and a people longing for choice and the comforts of domestic life. TV, like radio, phonographs, film, and even the car, has both reflected and reinforced an American desire for private life while sharing a mass culture. Few Americans have been willing to adopt a different way of living, even as they complain about the TV they are watching.

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18 Airplanes and Atoms in Peace and War

Civilian and military technologies have often advanced together. Although internal combustion was first developed for the factory and private transport, the military soon applied internal combustion to aircraft and tanks. Earlier, the Wilkinson boring machine, which made the Watt steam engine possible, was in large part developed for the manufacture of cannon. In the twentieth century, defenders of substantial government expenditures on military research pointed to significant civilian spillovers—although, in recent years these crossovers appear to be smaller in number, as military and civilian technologies diverge.

Military research on both airplanes and atoms solved complex technical problems and made widespread civilian application possible. Both stories start outside the military sector. The airplane was developed to facilitate travel, photography, and thrill-seeking. Only after private innovators had solved the most fundamental problems of flight did armies become interested—and this was only as war loomed on the horizon. Both World War I and World War II led to massive increases in research expenditure, which advanced airplane technology by leaps. The role of airplanes in war quickly became so central that even in peacetime the military devoted vast sums to improving aircraft performance—though airpower would only prove decisive in war when one side had a significant advantage over the other. Civilian aircraft borrowed heavily from fighters and bombers, and later would adopt the jet engine, also developed for the Air Force. Indeed, most airplane manufacturing enterprises survived on military contracts until after 1945.

Applied nuclear research in the military built on decades of scientific inquiry. The emergence of aerial bombing in World War I, and its widespread use on industrial and civilian sites in World War II, set the stage for the dropping of the atom bomb on two Japanese cities in August 1945. The devastating power of atomic fission, along with the rivalry and mistrust fostered by the cold war, led to a nuclear arms race. Partly to justify massive expenditures for ever more sophisticated nuclear weapons and 'delivery systems,' governments also sponsored research into nuclear power. Success there has proved to be a mixed blessing; it has come to provide a significant proportion of the world's electricity, but serious environmental risks remain.

Learning to Fly

Humanity has been fascinated with the idea of flight for millennia. Unable to duplicate the natural flight of birds, there were two ways in which humans could hope to fly. The first involved lighter-than-air craft, requiring knowledge both that the atmosphere had mass and that there were gases that were lighter than air—these principles were understood only in the eighteenth century. The second possibility, heavier-than-air craft, necessitated an understanding that with a sufficient forward motion air passing beneath an appropriately designed wing would provide upward pressure that would keep the plane in the air.

In 1783, both hot air and hydrogen balloons appeared for the first time in France. Within a decade, the military used balloons for reconnaissance. The vagaries of the winds prevented them from serving any commercial use. There were many experiments with methods of propulsion, including the use of steam by Henri Gifford in 1852. Success, though, came only with the development of internal combustion engines, which had a much higher power-to-weight ratio than steam. This engine, coupled with a redesigned cigar-shaped balloon and an appropriate propeller, made the *dirigible* (the French word for steerable) balloon a reality in 1884. Soon Ferdinand Graf von Zeppelin of Germany was the most famous name in airship design. He had first observed balloons during the US Civil War and made his first ascent in Minnesota in 1863. Zeppelin built ships of a rigid external frame, with the passenger area as an integral part of the design, and numerous internal balloons to prevent the frequent occurrence of one leak causing a ship to crash.

Such airships proved useful for both reconnaissance and bombing during World War I. Both military and civilian interest remained high during the interwar period in Britain, Germany, and the United States. However, because hydrogen gas is highly flammable, the dirigible was very susceptible to fires. The spectacular explosion of the *Hindenburg* at Lakehurst, New Jersey, in 1937 brought this era to an end—though advanced dirigibles are used today for televised sporting events and may be employed for transporting large objects, especially to remote locales.

In the meantime, there were dramatic improvements in heavier-than-air craft. Nineteenth-century experiments with gliders led to significant advances in wing design and steering. Orville and Wilbur Wright practiced with gliders for years before they attempted powered flight. Still, the airplane was somewhat slower to develop than the dirigible because it demanded a much more powerful engine relative to its weight. Engineers have estimated that an aircraft required at best no more than eight kilograms per horsepower. The best engines in 1880 weighed two-hundred kilograms per horsepower; by 1900, thanks to the development of the automobile, this ratio was four to one; the Wright brothers would power their first airplane in 1903 with an engine with a ratio of six kilograms per horsepower (Figure 18.1).

It is tempting to view the Wright brothers as lucky amateurs succeeding where esteemed scientists had failed. The Wrights did not receive much formal

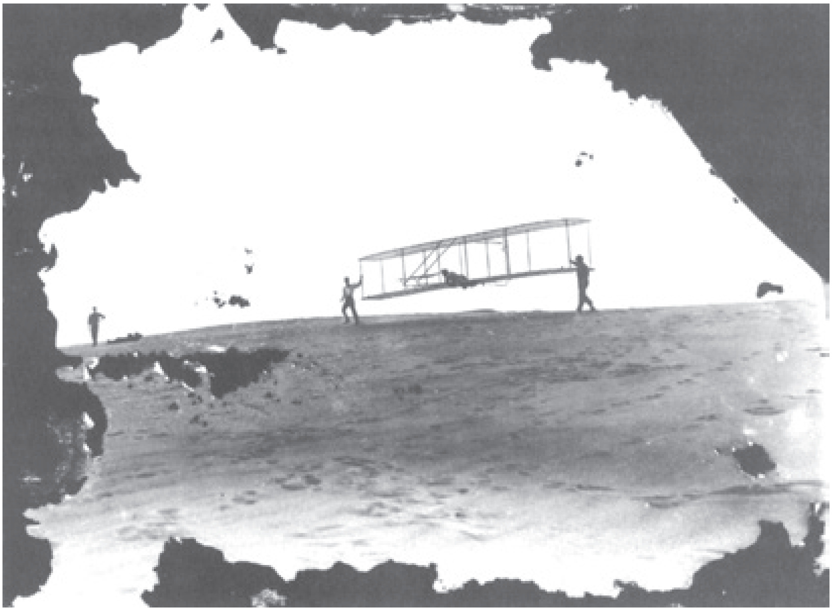

Figure 18.1 Orville Wright pilots with brother Wilbur at his right and Dan Tate at his left, Kitty Hawk, North Carolina, 1902. The Wright Brothers experimented with gliders for years before attempting powered flight.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

education, but they acquired considerable technical expertise (and much money) while running their Dayton, Ohio, bicycle shop. The Wrights were devoted to the scientific method. Beginning with kites, and then advancing to gliders, and often using a homemade wind tunnel, they tested various wing and propeller designs and carefully recorded their results. Their most significant discovery was that the addition of an adjustable tail fin gave them a dramatic improvement in control. Only with this success did they finally turn to building their own engine.

The Wrights' success at Kitty Hawk, North Carolina, went largely unnoticed at the time. Over the next years, they steadily improved their design, and became able to make controlled turns and to stay in the air for hours. A demonstration in France in 1908 finally overcame the public's skepticism. Then numerous inventors on both continents turned their attention to flying, often with the support of the local military establishment.

A Revolution in Personal Transport

By 1909, flights of 20 miles were common, and one plane even crossed the English Channel that year. By 1911, seaplanes had been developed, and aircraft had both taken off and landed from ships. The engine itself was a focus of much innovative effort. Airplanes required engines that eliminated engine knock (premature combustion), which was only an annoyance to car drivers but could be deadly for pilots. Airplane engines also had to be able to compress air at high altitudes. By the end of World War I, airplane engines were ten times as heavy and one-hundred times as expensive as their automotive cousins. Nevertheless, airplane production was still relatively inexpensive, allowing many small firms to try their luck at developing a better airplane. A firm could launch a new design for about $200,000 in the 1910s, versus millions in the 1930s, hundreds of millions in the 1950s, and billions in the 1970s.

Early development, however, depended not on the civilian but on the military sector. World War I may have accelerated aircraft development by decades. There were only 5,000 airplanes in the world in 1914, and their primary commercial use involved daredevil displays at county fairs. Only 49 planes were produced in the United States that year. By the end of the war in 1918, another 200,000 aircraft had been built worldwide. All of the belligerents funded research programs. By 1918, airplanes could reach 15,000 feet, and the largest bombers had six engines and a wingspan of 150 feet. Their impact on the outcome of the war was nevertheless limited.

In the United States, the war had two further lasting effects. First, under the strain of war, the government pressured firms into sharing patents (forming a patent pool); this policy provided a firm base for interwar technical development. Second, Americans gained vital technical expertise from European immigrants such as Anthony Fokker and Igor Sikorsky. Sikorsky moved to the United States in 1919 because of political uncertainty in Russia; Fokker followed in the 1920s because the United States after the war seemed the most promising locale for airplane manufacture. These circumstances assured that the United States would be the site of most significant developments in airplane technology after 1918. The superiority of the United States was signaled when a team from the United States Air Force flew around the world in 1924 (in 175 days), and Charles Lindbergh flew solo across the Atlantic in 1927.

During the interwar years, airplanes improved on several fronts. The first was stressed-skin construction. By taking advantage of new structural materials, the outer shell of the plane could be made load-bearing, eliminating the internal struts that had characterized early aircraft. Whereas wood was still the primary building material in 1925, metal was dominant a decade later. Another innovation was the replacement of water-cooled engines with air-cooled engines. This simplified design reduced costs by significantly decreasing the weight of the engine and facilitated much faster speeds. After considerable testing in wind tunnels, engines were moved to the leading edge of the wing, and new cowlings (engine covers) designed. Wing flaps allowed heavier and more powerful planes to land safely. Notably, as with many of these innovations, wing flaps were important only in concert with other changes. The variable-speed propeller (1932) made possible differing cruise and takeoff speeds. Instruments were developed; the first ‘blind’ flight occurred in 1929, and instrument flying became common in the 1930s. Pilots had often crashed in storms before instruments became common. Other innovations included de-icing systems and pressurized cabins.

The military, especially the United States Navy, continued to stimulate most innovation in the interwar years. Boeing, Douglas, and other manufacturers of the time relied on high-profit Navy orders to support research and development. At that time, firms often modified planes built for the military for civilian use. Requirements for engine maintenance were reduced from once every 50 flight hours during the war to once every five-hundred by 1936, primarily to serve civilian aviation. The government also supported the development of commercial aviation: It built airports, charted airways, designed safety laws, established a weather service, and set up a transcontinental system of beacons for night flight.

As a result, commercial aviation became a reality in the 1920s, although to a very limited extent. The government established airmail in 1918 and from 1925 contracted this service to private airlines that relied primarily on the mail business. (The American government had set a precedent by subsidizing steamship companies with mail contracts a century earlier.) Passenger service remained a sideline until the late 1930s. American, Delta, Northwest (now part of Delta), and United Airlines all emerged in the late 1920s, often as divisions of plane manufacturing companies. After scandals involving government awards of airmail contracts, and a brief experiment with mail delivery by the army (in which 12 pilots died), the airlines were separated from the manufacturers by antitrust action in the 1930s.

Commercial aviation would come of age in the 1930s. Charles Lindbergh's solo flight across the Atlantic in 1927 established public confidence in the airplane and caused a surge in investment in commercial aircraft. The Douglas DC-3 of 1936 was the first of the new generation of airplanes. The cost per passenger mile of operating that plane was one-quarter of that in 1929. It was quicker, could fly farther, and could carry as many as 28 passengers. It was also much safer. Reacting to the public horror over earlier crashes, including the one that killed football hero Knute Rockne in 1931, designers pursued every conceivable safety measure. The craft was so well built, in fact, that DC-3s would still be in the air well over half a century later. As a result, airlines were able to provide passengers with the combination of price, speed, comfort, and safety that made air travel commercially viable. The first profitable passenger-only route opened between New York and Chicago in 1936. Commercial aviation (though not the research of airplane manufacturers) had finally emerged from military support and government mail contracts to stand on its own. While airplanes carried only 6,000 passengers in the United States in 1926 and 173,000 in 1929, the figure for 1941 was 4 million.

If the 1930s were a decade of dramatic product improvement in airplanes, the 1940s would see process advance. Assembly line production of a handful of engine and airframe designs replaced the competitive batch production of the pre-DC-3 era. The transition to mass production was encouraged by military

Figure 18.2 Ford's Willow Run assembly line for the four-engine B-24 bomber, 1940s. Mass production technology made America the 'Arsenal of Democracy.'

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

demand during World War II (Figure 18.2). In the postwar era airplane production would be concentrated in just a handful of companies worldwide—in part because these companies financed costly research that developed bigger and faster planes that could fly farther, while further reducing the cost per passenger mile flown.

The Jet Versus the Piston

Long before the full potential of the propeller/internal combustion airplane had been achieved, some researchers began working toward the jet. As early as 1934, propeller planes could reach a speed of 440 miles per hour. Aerodynamic theory suggested that much higher airplane speeds were possible, but propellers could not withstand them. Regarding range and size, however, the propeller-driven format could still achieve much. Long-range bombers, developed during World War II, would lead to a variety of postwar four-engine propeller craft, which would cut in half the cost per passenger mile on busy domestic routes and significantly extend the possibilities in intercontinental flights. Still, many visionaries did not wait for these advances before beginning to study the jet.

Water turbines designed to produce electricity had already prefigured the basic design of a jet engine. In power stations, water pushed upon the blades of a turbine, which turned a generator. In the jet engine, combustion caused the plane to move forward by forcing a jet of air out the rear of the engine; this jet turned a small turbine, which powered a compressor that pulled the necessary air into the engine. In the 1930s, Frank Whittle in England struggled with skeptical government and private investors to overcome myriad design problems. As war approached, the British government provided a burst of funding that resulted in the first practicable jet engine in 1939 (Figure 18.3).

It was only at the end of World War II, after six years of intense competition between the belligerents (all of whom recognized that a jet, with much higher speed and range, would provide an immense military advantage), that the complex problems of jet propulsion were reaching a solution. Germany would produce jet aircraft but too late to have much effect before the war ended. Although military application of the jet engine was rare until the 1950s, by 1945 the jet was far enough advanced to be obviously the aircraft engine of the future.

Boeing, at the request of the army, became the first American firm to work on the jet in 1943. It thus started several years behind European innovators. Both the British (with the de Havilland Comet) and the Soviets introduced

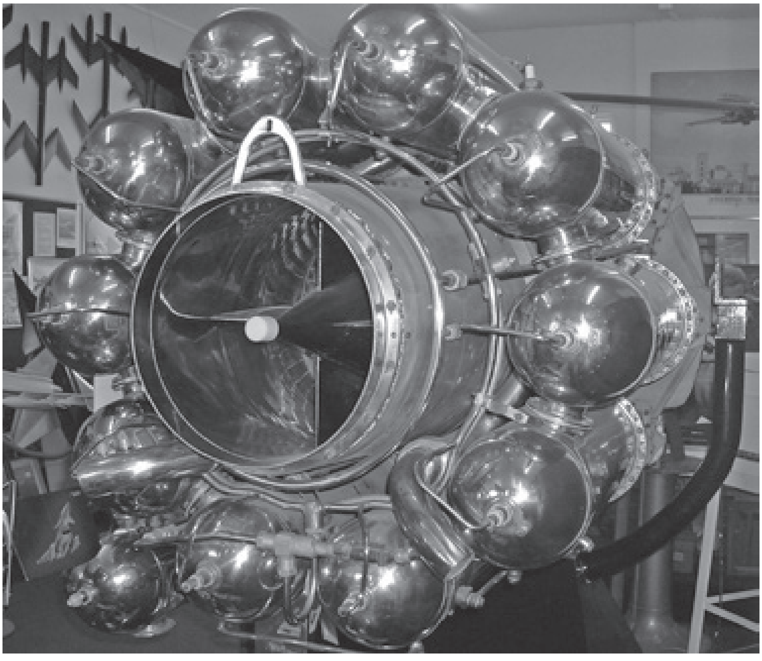

Figure 18.3 Whittle jet engine W2-700 that powered jet flight in 1939.

Credit: *Wikimedia. Wikimedia Commons, Photograph by Farnborough.*

jet aircraft before the Americans in the 1950s. However, American firms had developed much larger industrial research establishments than their British competitors. These possessed the range of experts necessary to solve multifaceted design problems (some of which became apparent only after the Comet crashed more than once). Americans also benefited from the mushrooming cold war defense budget: By the 1960s, the military financed 90 percent of American airplane research. By the time the Americans entered the commercial jet market, they were able to build larger, more powerful planes able to achieve even higher speeds than their British rivals (550 miles per hour versus 490). Thus, when the Boeing 707 launched in 1958 and the Douglas DC-8 in 1959, they immediately became the dominant aircraft in the world airplane market.

The jet engine provides good evidence of the indeterminacy of the timing of innovation. Advances in materials, fuels, and aerodynamic theory set the stage as early as 1930. A considerable research effort then could have accelerated development by a decade. Due to its complexity, however, without the war, the jet would likely not have been developed for a decade or more.

World War II and the Birth of the Bomb

The growing role of aerial warfare stimulated the development of devices for detecting airborne assaults, as well as larger, more accurate bombs. Radar played a significant role in World War II. As early as 1922, Marconi demonstrated that radio waves could be used as a detection device because they reflected off objects in the sky back to the transmitter. Because of the immediate threat of war, Britain and Germany took the lead in radar technology in the 1930s. By the start of the war in 1939, both sides had radar devices that could warn stationary installations of approaching craft. They were still too imprecise to give fighter planes much aid in locating enemy planes. The British developed radar that could be used in planes during the war and shared that technology with the United States. All this was a continuation of the arms race that began in the generation before World War I, as we saw in Chapter 11.

Scientists soon recognized that radar could potentially guide bombs to their targets. The proximity fuse, built around a small radar device, caused a bomb dropped from a plane to detonate at a set distance from the land target; this prevented bombs from exploding either too early or too late. Because the enemy's bases, airfields, research labs, and production facilities were often located near civilian populations, and bombing was not a precise activity (the proximity fuse only guaranteed that the damage was maximized, not that it was to the correct target), noncombatants automatically became much more common victims than before.

In the midst of a war in which the stakes were either total victory or unconditional surrender, few balked at the option of using the newfound technological capability against both civilians and targets of any conceivable economic value. Late in the war, for example, the Allies killed forty-five-thousand civilians in a ten-day bombing onslaught on Hamburg.

It was in this environment that the atomic bomb was developed. As with the jet engine, decades of research had laid the groundwork, but a massive research effort during the war was required to move from scientific principle to a practicable bomb. In 1919 in England, Ernest Rutherford performed the first artificial nuclear transformation when he induced the separation of a nitrogen atom into hydrogen atoms. In 1932 at Cambridge, England, the lithium atom was split into helium atoms by electrically accelerating a proton projectile. This provided the first evidence of the $e = mc^2$ formula propounded theoretically by Einstein in 1905. These were experiments in pure science. Rutherford himself would die in 1937, convinced that nuclear power would never be of practical use.

From the late 1920s, advances had depended on increasingly expensive linear accelerators, which accelerated electrons to very high speeds so that the effect of their impact on atoms could be measured. When the successful application of atomic theory seemed so far off, governments balked at financing such facilities to the extent necessary.

The onset of World War II advanced nuclear research by decades. At the beginning of the war, Germany appeared to have a dangerous lead. In 1938, Otto Hahn and Fritz Strassman showed that they could transform matter into energy by firing neutrons at uranium. They found that a chain reaction was possible, in which the splitting or fission of one uranium atom would release neutrons that would, in turn, cause other atoms to break up. These discoveries led to a German nuclear research program. In response, in 1939 many scientists (many of them refugees from central Europe) wrote to President Roosevelt imploring him to finance a significant nuclear research effort. One of these scientists was the German-born Albert Einstein. Eventually, Roosevelt agreed.

It is ironic that the German research effort never progressed far. In the first years of the war, the German government was confident of an early victory, and thus saw little reason to fund a costly long-term project. In the later years, Allied bombing made it impossible to construct the necessary industrial apparatus. Moreover, many German scientists claimed after the war that they had deliberately dragged their feet for fear of what the Nazis might do with such a weapon.

Scientists soon recognized that only the rare Uranium 235 isotope would generate the desired chain reaction. In 1940, two British scientists calculated that if a small 'critical mass' (perhaps less than a pound) of this isotope could be isolated, a bomb could be created with the explosive potential of several thousand tons of dynamite; they also recognized that radiation might kill people miles away from the blast. This discovery led to an immense effort to isolate uranium 235.

The problem was that only .7 percent of natural uranium is of the isotope 235. Scientists who had struggled to isolate minute quantities of the isotope were asked to design large-scale isolation procedures in both Britain and the United States. Simultaneously, scientists in both countries discovered that when they bombarded the more common uranium 238 with neutrons, it produced a new element, which was named plutonium, which itself had even greater explosive potential than uranium 235.

A race for the critical mass of fissionable material was on. Speed rather than economy dominated what became known as the Manhattan Project. Five distinct paths were followed: Uranium 235 was isolated by a gaseous diffusion method, by a centrifuge, and by electromagnetic separation. Plutonium was produced from a chain reaction performed with the use of either heavy water or graphite. Americans soon monopolized these efforts. Roosevelt at first authorized $500 million for research; the figure topped $2 billion by the summer of 1945.

For security reasons, the work was compartmentalized: Scientists working on one aspect of the problem were to know nothing of what others were doing (although scientists ignored this order because of the need to share information). One team in Chicago—of which Enrico Fermi, the Italian refugee, is the most famous member—became the first to achieve a sustained chain reaction in December 1942. They constructed a pile of uranium pellets pressed into blocks of graphite under the football stadium at the University of Chicago. Cadmium bars, which would absorb neutrons and thus prevent a critical mass from starting a chain reaction, were gradually removed while Fermi used a slide rule to calculate the results of the experiment. After briefly announcing to a hushed crowd of scientists that the reaction was self-sustaining, he waited 20 minutes before ordering the cadmium rods to be replaced to end the experiment. There were two scientists near the pile ready to douse it with a cadmium solution if something went wrong. The team had initially hoped to experiment at the Argonne Laboratory outside Chicago, but this facility was not ready in time. That such an experiment was undertaken in a major population center is indicative of the wartime fear that guided the Manhattan Project.

Fermi's accomplishment was an essential ingredient for both power plants and bombs. For a bomb, the next trick was to set off an uncontrolled chain reaction at just the right moment. One solution involved firing a uranium 235 projectile into a mass of uranium 235. With plutonium, however, this method proved unworkable: Instead, explosives surrounding a mass of plutonium would force the plutonium to implode, surpass the critical density, and thus explode.

Scientists could still provide only the roughest estimate of how great the explosion might be and were even less able to predict the potential radiation release. When a plutonium bomb was tested at Alamogordo Air Base in New Mexico in July 1945, most thought the blast would be the equivalent of a few hundred tons of dynamite; it was instead close to twenty-thousand. When the bomb was dropped on Hiroshima, it was estimated that 10,000 would die; instead, as many as 80,000 were killed almost instantly (with that number nearly doubling in the three months following, due to deaths from radiation and other bomb-related causes), and 96 percent of the city's buildings were damaged or destroyed.

With Germany's surrender in April 1945, the original motive for the Manhattan Project disappeared. Some scientists hoped to keep the bomb a secret and not use it. However, the war with Japan continued into the summer of 1945. Others lobbied for a public demonstration of the A-bomb to frighten Japan into surrender. Fears that such a bomb might fail to explode or would fail to impress the Japanese if fired on a barren test site caused this idea to be shelved. Instead, on 6 and 9 August 1945, two bombs were dropped on the Japanese cities of Hiroshima and Nagasaki (Figure 18.4). Debate continues to this day as to whether the cost in civilian lives was justified in terms of the high number of casualties that would have occurred if the United States had invaded Japan. Were the Japanese edging toward surrender anyway? Were two bombs necessary? Might less populous targets have served as well? The use of these bombs was the culmination of a trend toward total war (Chapter 11), the mobilization of an entire nation's technological and economic resources and the elimination of any division between civilian and military targets in pursuit of the need for unconditional surrender.

Although the atom bomb ended one war, it almost immediately started another. The Soviet Union had borne by far the most casualties during World War II and had emerged victorious (albeit with help from allies). With conquests in Eastern Europe, the Soviet Union felt secure as never before. Then the United States unleashed this new weapon, and the world changed. When the Soviet Union attempted to match America's nuclear potential, the Cold War began.

The Technology of the Balance of Terror

Although the Soviets and the West were allies after the Nazi invasion of the USSR in June 1941, the Americans were unwilling to share their nuclear research plans with the communists. We now know that a handful of western scientists informed the Russians of the general nature of British and American research efforts as early as 1942. Some allied leaders, and leading physicists such as Neils Bohr and Albert Einstein, believed that hiding the plans for the A-bomb from the Soviets would foster postwar suspicions. Still, US policymakers were themselves mistrustful of the Russians and thought that the US-Soviet alliance against the Nazis was only temporary. The western allies were worried about Soviet designs on Eastern Europe; Soviet troops were stationed throughout that region at the time of the atomic bombs. Some have suggested that the two bombs were dropped in large part to send a message to the Soviets that postwar aggression in areas such as Iran would not be tolerated.

Although President Truman promised in the aftermath of Hiroshima that the United States would guard the bomb in the interests of humanity, US allies immediately set to work on their own bombs. British and French scientists had played a valuable role in the Manhattan Project; those governments recognized that they had not always agreed on wartime priorities with the Americans and they set their scientists to work on British and French bombs. Many leading physicists argued for the internationalization of nuclear technology, and the idea gained much public support. Governments, however, responded only by being increasingly secretive about their research efforts.

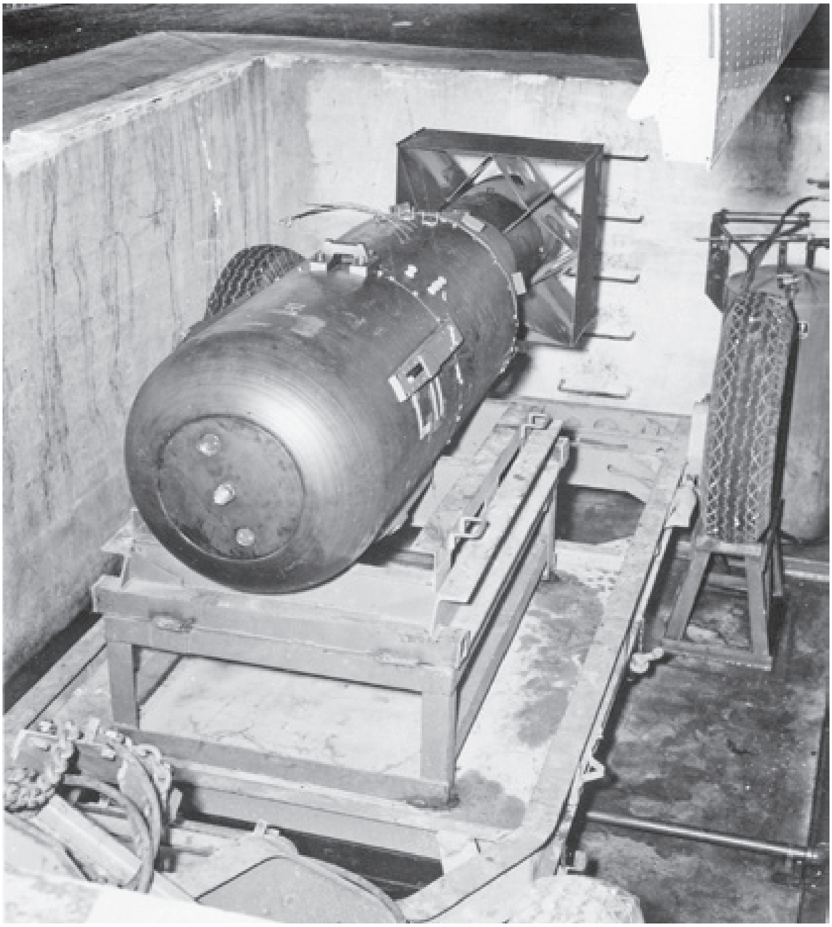

Figure 18.4 "Little Boy," the atomic bomb that destroyed Hiroshima, in bomb loading bay.
Credit: *National Archives and Records Administration.*

In 1945, Western officials predicted that the Soviets were at least a decade away from having their own bomb. The Soviets, however, had launched their own Manhattan Project after Hiroshima and succeeded in exploding their first bomb in September 1949. This ended any hope of international stewardship of atomic weaponry.

Even before the war, scientists had recognized that fusion—the joining of (generally small) atoms to create a new atom—could potentially release much more energy than fission—the destruction of a (usually larger) atom. It would require very high temperatures to induce fusion, however. As fission became possible, scientists recognized that a fission explosion could trigger a fusion explosion. The United States produced the H-Bomb in 1952, with an explosive power of 15 *billion* tons of dynamite. The Soviets, however, were not far behind and had a similar device a year later.

As soon as the Soviets joined the atomic club in 1949, some claimed that the bomb would never again be used because nuclear war was just unthinkable. Increasing awareness of the dangers of radiation reinforced this view. Although observers noted that thousands who had survived the A-bomb explosions later died a horrible death due to radiation poisoning, authorities believed that the radiation was localized. However, when the hydrogen bomb was tested on Bikini Atoll in the Pacific in 1954, fishers on a Japanese fishing boat one-hundred miles from the blast were killed by radiation poisoning. After years of negotiation, the United States, Britain, and the Soviet Union signed a treaty banning atmospheric testing in 1963 (Figure 18.5).

Figure 18.5 Atom bomb test, Frenchman's Flats (Nevada) testing ground 1951. Soldiers were used as guinea pigs to test for the radiation effects of an atomic explosion.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Scientists and politicians gradually came to understand that nuclear war could make the earth uninhabitable. Nonetheless, Cold War hostilities and crises led world leaders periodically to think the unthinkable. When, in 1962, the Soviets attempted to establish launch sites in Cuba, from which most of the continental United States would have been subject to nuclear attack, the United States appeared ready to risk nuclear war. The Soviets backed down but convinced the Americans to withdraw from their missile sites in Turkey.

Both sides recognized that a few nuclear bombs could destroy millions of people, and this fact alone should have been a deterrent to war. However, neither antagonist could count on the rationality of its enemy. Thus, both powers continued to pour billions of dollars into research and development. This meant at first bigger (reaching the equivalent of one-hundred million tons of TNT) and more bombs. Stockpiling large numbers of nuclear weapons was part of a strategy of proving to the enemy that the nuclear power could withstand a 'preemptive' or first strike—at least in the sense of having sufficient bombs left after such an attack to retaliate. By 1980, the Americans had 9,200 nuclear warheads as compared to the Soviet Union's 6,000. The guiding principle was *mutually assured destruction* or MAD. To avoid war, the superpowers had to prepare for global annihilation. The Americans and Soviets occasionally agreed to reduce their arsenals but never below a level that could ensure mutual destruction.

MAD depended not only on a massive stockpile of bombs but also on reliable delivery systems. Standard bombers dropped the Hiroshima and Nagasaki bombs. Their limited range had meant that American forces had to establish airstrips within a couple of hundred miles of Japan. In the postwar years, much effort was expended on increasing the range and size of bombers. The American B-52 bomber of 1954 (later versions of it are still in service) could fly for ten thousand miles without refueling and reach a speed of 600 mph. Still, the B-52 might be shot down before reaching its target. As bombs became smaller, it became feasible for nuclear powers to rely instead on missiles. Missile technology grew out of the rocketry experiments of the American Robert Goddard in the interwar years, and the German Wernher von Braun's V-2 rocket. Used by the Nazis in the final stages of the war, the V-2, with a range of two hundred miles, reached speeds of nearly 3,500 mph upon impact. By 1953, the United States had deployed the short-range Ajax missile. The first of the intercontinental ballistic missiles (ICBMs), the Atlas, was launched in 1960. It had a range of five thousand miles and could hit within two miles of a target. The ICBMs became much more sophisticated in the 1960s and 1970s with improved electronic targeting. Missiles increasingly were equipped with several warheads (multiple, independently targetable reentry vehicles, or MIRVs).

In 1957, the United States launched its first nuclear-powered submarine, equipped with the Polaris missile. This new generation of submarines had the advantages of being submersible for extended periods and nearly impossible to detect (because they did not 'breathe' as diesels did). Even more than the nuclear bombers and ICBMs, they were weapons that deterred a nuclear attack because they were 'survivable.' The triad of B-52, ICBM, and nuclear sub guaranteed that the enemy could not stop all of the bombs aimed at it.

MAD did help to prevent war between the Soviets and the West for 45 years. However, its logic encouraged a costly arms race. More weapons increased the potential for a first strike, requiring still more to assure 'survivability.' As the speed and accuracy of delivery increased with the introduction of long-range missiles, the danger of accidents grew. If one power merely *thought* the other was launching an all-out nuclear attack, that country would feel obliged immediately to launch its own weapons. From 1950 through the Cuban Missile Crisis of 1962, American anxiety about the bomb was most intense. To both allay the fears of ordinary Americans and convince the enemy that the United States would use the bomb if forced to, the government sponsored an elaborate program of civil defense. Children in school participated in drills in which they crouched under their desks and covered their heads with their hands. A 1950 Civil Defense Agency poster advised adults to leap into "any handy ditch or gutter" if they did not have time to reach a basement or subway. On a larger scale, there was talk of redesigning cities so that populations would not be so concentrated. Legislation in 1956 that funded the interstate highway system was justified in part as a means of getting populations quickly out of cities should an attack be imminent. In 1957, thousands of Americans built backyard 'bomb shelters,' equipped with food and designed to prevent entry by less prudent neighbors. Civil defense soothed people's fears by making them think that a nuclear war might not be the end of the world (Figure 18.6).

Since the 1980s some have advocated the development of a nuclear shield whereby incoming missiles might be shot down from satellites. Billions of dollars have been spent on research, though many scientists are skeptical that such a system could ever destroy all incoming missiles. If even a few missiles reached their targets, millions might be killed.

The collapse of the Soviet Union in December 1991 seemed, at first, to end the arms race. Military budgets in the West and Russia declined sharply at first. However, the emergence of the United States as the world's only superpower did not end the threat of weapons of mass destruction. Because plutonium is a natural byproduct of nuclear power generation, it is difficult to control access to this vital component of nuclear weapons. Biological and chemical weapons could provide another means for otherwise weak states and groups to intimidate or harm others, especially because they can be manufactured far more easily than nuclear weapons.

Adding to this anxiety was the appearance of new enemies, who many American policymakers believed could not be deterred from obtaining and using these weapons of mass destruction. The Iraq Wars of 1991 and 2003 raised the fear that a small state, run by an apparently irrational dictator, would use such weapons. Moreover, out of the Soviet defeat in Afghanistan emerged militant Islamic groups hostile to Western, and especially American, influence

Figure 18.6 Woman in bomb shelter, 1961. Note canned foods and bunk bed.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

in the Middle East. The hijacking and crashing of two commercial airliners into New York's World Trade Center towers in 2001 did not, of course, involve sophisticated weapons systems, but this outrageous attack on American soil led to renewed innovation in counterterrorist technology, and fears that terrorists would obtain and freely use weapons of mass destruction. This possibility became an argument for the renewed development of missile defense systems, to be used to shield the United States from groups who could not be deterred by threats of retaliation. Concerns remain that terrorists might either steal a nuclear weapon, build one with stolen plutonium or enriched uranium (these are far too expensive for terrorists to manufacture themselves), or merely explode a conventional device laced with radioactive material (or perhaps bomb a nuclear power facility, releasing radioactive material).

At the same time, quite apart from these security issues, new communications and other technology led to innovation in conventional weaponry. Global positioning systems (GPS) made it possible to determine one's exact position with the aid of a GPS receiver, which measures the time that it takes to receive signals from four of 24 GPS satellites. This was useful both to soldiers on the ground and to bombers trying to hit a precise target: In World War II and again in Vietnam most bombs are thought to have missed their targets. There was military interest in GPS from the time that the first satellites launched in the 1950s. The United States Air Force led a research effort in the 1970s and recognized that four satellites would need to be in view from any receiver to identify a precise location. Receivers do not interact with satellites but rather receive signals from these and compute location; they are thus only possible because of advances in computing power that allow small devices to perform complex calculations. The satellites themselves carry atomic clocks so that they can signal a precise time for their location. The first GPS satellite launched in 1978 and the system was completed in 1994. More than nine-thousand GPS receivers were used during the 1991 Gulf War to help American soldiers navigate in the desert. Though there had been limited civilian interest in the 1970s, the Air Force faced pressure to allow private use of the technology once it existed; the shooting down of a Korean airliner with Americans onboard that had entered Russian airspace in 1983 showed how valuable civilian use could be. GPS receivers have become commonplace since, and smartphones now act as receivers.

A variety of sensors on satellites and aircraft can now detect targets in fantastic detail from great distances. Night-vision detectors intensify faint visible light or pick up heat emitted by the enemy with infrared sensors. Advancements in radar in the 1990s, especially phased-array radar devices, have vastly increased the range of detection, and have made possible improved intelligence through eavesdropping on thousands of radio or telephone conversations (aided more recently by the controversial practice of gathering information from private email and social media communications). By the mid-1990s, the Joint Surveillance and Target Attack Radar System (JSTARS) was available on aircraft to scan the ground for targets. New guidance systems mounted on the noses of navigable bombs made possible far more accurate bombing. While these so-called smart bombs were used during the Vietnam War (and primitive versions were available in World War II), they became far more sophisticated in the 1990s. In some cases, soldiers use images from television cameras on smart bombs to guide them to the intended target. On others, laser beams light targets and sensors lock onto the reflections, guiding bombs to their destinations. The third type of smart bomb uses infrared sensors to latch onto the heat produced by the target. GPS systems are also used to guide bombs to their goals. The latest smart bombs often employ multiple techniques. Smart bombs may not always hit the 'right' target, but they have made possible high-altitude bombing, protecting the flight crew from anti-aircraft fire.

Another recent innovation is stealth technology, making aircraft undetectable (or at least difficult to detect) by radar or sonar. The military has longed for stealth aircraft since World War II. Still, only in the 1960s, with the development of such materials as carbon-fiber composites and high-strength plastics, did it become possible to construct planes that both possessed structural strength and were capable of evading radar. Stealth was dramatically enhanced with new plane designs that reduced right angles, sharp curves, and large flat surfaces. Stealth aircraft also avoid infrared detection by abandoning heat-producing afterburner engines. This requirement made stealth aircraft incapable of supersonic flight. Nevertheless, the US government developed the F-117A fighter in 1983 and the intercontinental B-2 bomber in 1989. The B-2, which looks like a single flying wing, flew successful bombing missions to the Balkans in 1999 and Afghanistan in 2001—directly from American bases.

Adding flexibility to American military power has been the cruise missile, developed from the 1970s. Unlike the ballistic version, the cruise missile is powered by jet engines and travels along a low, level flight path that allows for traditional navigation with wings, rudders, and flaps. Whereas the ballistic missile is detectable at launch, the low-flying cruise missile can more easily evade air-defense screens. Cruise missiles can be launched from the air or ground, or at sea (Figure 18.7).

Although developed first during World War I, and used extensively in Vietnam, unmanned aerial vehicles (UAVs) or drones have become much more important since the 1980s with developments in the miniaturization of electronic devices. They have been used extensively for military reconnaissance. There are thousands of drones of various sizes in the United States Air Force arsenal. They range in wingspan from the 6–inch Black Widow to the 116–foot Global Hawk. While most are used for intelligence, some of the larger UAVs have been equipped with missiles. Nonlethal weapons of many kinds have also been developed, including lasers to temporarily blind enemy combatants, and filaments used to short-out electricity. In recent years drone technology has entered the civilian sphere. Aerial photography has proven very useful, and many firms are experimenting with delivery services using drones (Figure 18.8).

Along with the now ubiquitous use of computers to coordinate supply and combat, these military innovations seemed to be leading to a 'revolution in military affairs.' Precision and often remote strikes at any identified target appeared to negate many of the rules of war. Thus, some observers believed that military conflicts could become predictable and nearly

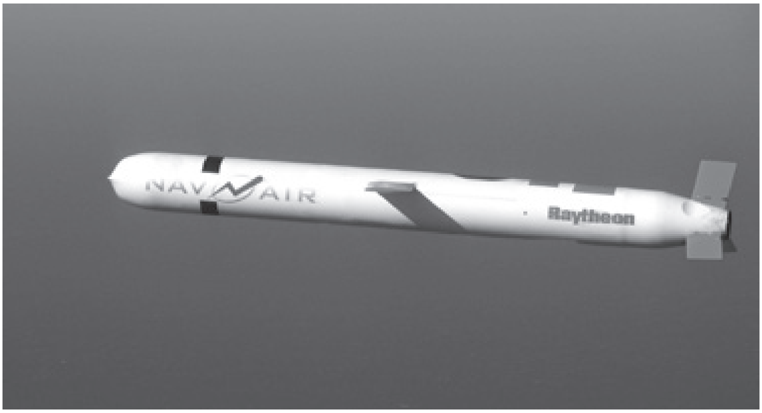

Figure 18.7 Tomahawk Cruise missile, 2002.

Credit: *United States Navy.*

Figure 18.8 US Army's MQ-1C Warrior UAV, 2005.

Credit: *United States Army.*

cost-free in loss of life. Improvements in aircraft carriers and accurate long-distance bombing made it possible for the United States quickly to deploy overwhelming power in the Balkans in 1999, and against Iraq in 1991 and 2003 without significant US casualties. However, as in the past, the technological advantages of one side (in this case, the American) can quickly turn to the benefit of an enemy when new precision and flexible weapons become available on a global scale. Moreover, the advantages of a high-tech military can be neutralized by 'asymmetrical warfare,' whereby a poorer adversary can avoid direct conflict by using terror, suicide attacks on 'soft' targets, sabotage, or other means to attack or defend against the United States and its allies.

President Eisenhower warned of the dangers of the military-industrial complex in the 1950s. The armed forces had already come to depend on a small number of firms (but, through these, on hundreds of subcontractors) for technical advances. The complexity and often secrecy of this technology made it difficult to monitor high-tech contracts. More dangerously, these companies had a powerful financial incentive to lobby in a variety of ways in favor of certain technologies—and perhaps even certain foreign policies that would increase the need for such technologies. As employment in the military-industrial complex expanded, many members of Congress faced an incentive to protect the jobs of constituents independent of concerns regarding the value of the weapons they built.

Nuclear Power

Power production was the most obvious but by no means the only nonmilitary application of nuclear science. Some of the others include radiation therapy, carbon 14 dating in archaeology, and radiation-sensitive gauges in precision manufacturing. Radioactive isotopes allow scientists to trace the respiratory process in plants, and engineers to find leaks in pipes, and provide the mechanism by which smoke detectors work. Crime labs use radioactivity to test for gunshot residues. Photocopiers and videotapes also depend on nuclear technology. Deep space probes, which have visited the outer planets of our solar system and beyond, have relied on plutonium-based generators.

Nevertheless, nuclear power has had by far the most significant economic impact and has been the most controversial. Because minuscule amounts of uranium could produce massive amounts of energy in a bomb, early nuclear power advocates hoped for electricity 'too cheap to meter.' The bomb program had already shown that chain reactions could be induced. The only question was whether power could be generated at a cost comparable to coal or oil. Each nation with nuclear capability (and this number steadily grew, as other developed countries joined the chase) pursued its own research program, and thus a variety of different reactor designs emerged during the 1950s. All used the heat of the reaction to create steam that powered turbines, but the reaction itself could be based on uranium or enriched uranium with or without plutonium, and could be controlled by water, heavy water, or a variety of other substances. The United States in 1953 removed wartime restrictions on the sale of atomic technology suited to power production. Other nations followed similar policies. Thus, as nuclear power became practicable in the mid-1950s, it was immediately made available to less-developed countries. These found themselves, indeed, faced with a bewildering choice among different reactor designs.

Only in the 1960s did questions arise over the safety of nuclear power generation. The industry responded that they over-engineered plants from a safety standpoint. The controlled reaction of a power plant is entirely different from the uncontrolled reaction of a bomb, and fears that a power station could explode were largely misplaced. Still, if heat is not taken away from the reactor core as it should be, the reactor will crack and release radiation; this is what is called a meltdown. As hundreds of plants were built worldwide, accidents did happen, and each threatened to release massive doses of radiation into the countryside. The meltdown of the Chernobyl reactor in the Soviet Union in 1986 might be viewed as merely symptomatic of the lax safety regulations that existed in a country with no protest movement. However, many saw the extensive contamination caused by that disaster as an inevitable consequence of nuclear power production. Although the utility that operates the Three Mile Island plant in Pennsylvania claimed that the 1979 accident there—the worst ever in the United States—hurt no one, many local residents complained of ailments, and the utility's insurance company paid out $14 million in claims.

No statistically significant increase in cancer was found in the neighborhood. Environmental cleanup cost about a billion dollars. Many worried that as reactors aged, cracks might develop allowing radioactive material to escape. More recently, there has been a concern that terrorists might target nuclear power plants.

Moreover, power plants must necessarily produce large quantities of radioactive by-products. In the 1950s, nuclear proponents hoped that science would eventually uncover some method of decontamination. In the meantime, these wastes have been stored at hundreds of sites worldwide. Some of these sites have proven much less safe than had been hoped, and surrounding land and water (and occasionally local communities) have become contaminated. Given that some of these radioactive substances have half-lives of a million years (that is, it takes a million years for them to lose half of their radioactivity), many wonder if we have not begun a gradual process of making our world unlivable.

There is the related question of dismantling plants. Due to the danger of equipment fatigue causing an accident, it is recommended that nuclear power plants be shut down after a life of thirty years. The first plant in the United States, at Shippington, Pennsylvania, was dismantled in the early 1990s. Costs of safe dismantling were higher than for the original construction. Robots have been wemployed to reduce the radiation effect on humans.

Despite these problems, many nations depend on nuclear power. In the early 2010s, there were more than four hundred and fifty nuclear power plants in 31 countries, providing one-sixth of the world's electricity. In the United States, about 100 plants—far more than in any other country—generated about 20 percent of the nation's electricity. Concerns regarding global warming have encouraged a rethinking of nuclear power, as have spikes in the price of oil. Still, no American utility had successfully launched a nuclear power project since 1974 before a handful of projects received regulatory approval after 2012. Globally, though, and especially in Asia, governments approved dozens of nuclear power projects in the early 2010s. Researchers continue to hope that fusion could generate power while generating hardly any radioactivity (and thus with no danger of meltdown), even though years of research have failed to achieve this goal (a fusion reaction would be so hot that no existing materials could contain it). Fusion would have the further advantage of relying on inputs such as deuterium, which is easier to obtain and lacks the weapons potential of uranium.

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19 The Postwar Advance of Technology

Technological innovation touched every corner of the postwar world. While most American consumers noticed the coming of television and VCRs, compact discs, jet travel, new synthetic clothing and plastics, and microwave ovens, the technological upsurge after 1945 also transformed the far reaches of farming, mining, and medicine. Although these innovations had roots in the 1920s and 1930s, many were developed during World War II. Depending on costly and complex research, they seldom were the invention of one individual or even of one team. Increasingly, innovation required not only the corporate research lab but government sponsorship and university research. These technologies offered a plethora of new goods and services, but they also transformed the way Americans worked. They accelerated the trend away from farming and mining, even reduced the proportion of Americans employed in industry, and set the stage for the modern service economy.[1]

We can survey only a few of the most important areas of technological advance here. We should recognize, though, that these technological trajectories were not as independent as they might seem. Plastics, for example, have revolutionized health care. As research effort expanded, the possibilities for combining advances in different fields to create new technologies exploded.

Industrializing Farms and Mines

As we saw in Chapter 7, nineteenth-century Americans pioneered many labor-saving machines. The postwar period saw a tremendous surge in the mechanization of the farm. One of the most significant improvements, the gasoline tractor, had become practicable only in the 1910s and 1920s; interwar improvements then paved the way for its nearly universal adoption. In the 1920s, the all-purpose tricycle tractor (which allowed tractors to pull cultivators for the first time) was fitted with pneumatic rubber tires (which improved fuel efficiency and flexibility). In the 1930s, power takeoffs and lifts made it possible for implements to receive power from the tractor. Still, by 1940 there were only 1.5 million gasoline tractors in the United States. The big surge occurred after the war (Figure 19.1).

Figure 19.1 Dustbowl, 1930s, Texas Panhandle: Years of drought caused topsoil to drift across the western United States and Canada. Cultivation techniques more appropriate to the soil and climate conditions were developed after World War II.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

Tractors revolutionized American agriculture. They replaced a great deal of both human and animal labor. Along with the replacement of horses by cars and trucks for off-farm transport, the tractor allowed the number of horses in the United States to fall from 27 million in 1916 to 15.4 million in 1938. This, in turn, released enough land (previously used to feed horses) to feed 16 million people.

The tractor paved the way for the harvester combine, which could both cut the crop and thresh the grain. Although primitive combines date from the nineteenth century, combines came to dominate American farming only after 1945. By 1956, there were over one million such devices on American farms. Previously, colorful crews of roving threshers had moved northward across the Great Plains helping farmers with their harvest. Various other machines were also designed for use with tractors.

The mechanization of other crops also increased after the war. The cotton-picking process had long frustrated farmers in the South. In the 1920s, John and Mark Rust of Texas patented a cotton-picking machine. They were fearful, however, of the potential of their invention to throw poor southern farmers out of work and they tried to adapt their machine to small farms and to restrict its use to cooperatives. In 1942, International Harvester began manufacturing a practical 'spindle' picker: When tiny spindles attached to a revolving drum contacted a cotton plant, cotton fiber became attached to the spindles. The fiber was then blown into a large cage. This machine could do the work of forty hand pickers and reduced the labor required to pick one hundred pounds of cotton from 42 worker-hours to 40 minutes. In 1969, a successful tobacco harvester was produced. Mechanization of sugar beet harvesting had begun to replace migrant labor (especially in California) by the late 1950s. A crew of three with the tomato harvester could do the work of 60 pickers by 1968 (Figure 19.2).

Rural electrification in the 1930s also opened up numerous possibilities for mechanization. Many farmers, to be sure, had previously installed small generators, but electric pumps, milking machines, and even refrigerators for dairy products would not see widespread use until low-cost electric power was extended to rural households as part of Franklin Roosevelt's New Deal in the 1930s.

In the postwar world, advances of a chemical/biological nature grew in importance. Until recently this research was dominated by the government agricultural research stations located in each state: Whereas machinery manufacturers could profit by selling improved machines, advances in seeds (and especially nonpatentable techniques of seeding or plowing) were not privately profitable. Government agricultural research stations had been cross-breeding plants for decades in an attempt to increase yields. Although this research mostly proceeded on a trial-and-error basis, advances in the scientific understanding of genetics guided researchers (plant growth hormones were identified in the 1920s, and synthesized beginning in 1934). In 1926, hybrid corn was developed, which more than doubled output per acre. Advances also occurred with

Figure 19.2 Mechanical corn picker, Iowa, 1939. Corn harvesting was a more difficult technical problem than was the case with wheat but was solved from 1939.

Credit: *Courtesy Library of Congress Prints and Photographs Division.*

respect to wheat, cotton, and many other crops. Emboldened by these successes, these government stations have since produced a steady stream of new varieties that increase yields, provide higher quality output, and are resistant to fungi and insects. Often, mechanization has only been possible because of the development of hardier strains (e.g. of cotton, sugar beets, and tomatoes) that ripened simultaneously. In recent decades, many have worried that the reduction in genetic diversity that has resulted from these research efforts may have limited our ability to cope with future environmental changes. Corporate industrial research labs have since the 1980s superseded the time-consuming process of cross-breeding by directly inserting genetic material into plants. When this genetic material comes from organisms that could never cross-breed naturally, concerns are raised that scientists may create crops that will have unimagined side-effects on the environment or human health.

One of the most important postwar developments was the widespread use of pesticides. DDT was developed in Switzerland in 1939. During World War II, governments increased their support of research in insecticides. DDT would be the basis for many postwar pesticides. Farmers were no longer defenseless against, among other pests, the plague of grasshoppers that had caused such devastation in the 1930s. It was soon discovered, however, that DDT and other pesticides had unforeseen adverse effects on the environment. Debate raged for decades as to whether DDT should be banned before this occurred in 1972. By this time, other pesticides with less harmful environmental effects had become available. Du Pont introduced the herbicide 2–4D during the war as well. This too was the basis for many postwar chemicals. The backbreaking work of weeding was now mostly unnecessary. Farmers spent only $3 million on insecticides and herbicides in 1940; by 1954 they were spending $170 million. The American government encouraged the export of these products, viewing them as exemplars of American success in innovation and seeking to use them to eradicate malaria in Italy and elsewhere; environmental concerns nevertheless limited efforts to spray extensive areas to eliminate disease.

Those engaged in raising livestock benefited from many of the new pharmaceuticals: Both sulfa drugs and penicillin decreased the incidence of livestock disease, and poultry were force-fed vitamins. From the 1940s, artificial insemination allowed bull semen rather than the bulls themselves to be transported around the world. Mechanical feeding of penned hogs and cattle, and especially chickens, caused this traditional farm job to appear more and more like factory work. Many have worried about both the health risks and ethics of factory farming: Animals have limited freedom of movement and diseases can spread rapidly among closely confined animals.

The advantages of all these changes have been evident in terms of delivering cheap food to millions in the United States and the world. Agricultural output per worker-year of labor increased 6 percent per year between 1950 and 1980, double the rate of increase in labor productivity in industry and services. Working hours expended per acre of cotton dropped from 99 in 1939 to 40 between 1962 to 1966, and in that same period decreased from 8.8 to 2.9 for an acre of wheat (Figure 19.3).

The lifestyle of American farmers changed even more than their productivity. The relative isolation and self-sufficiency of farms and farming communities were ended by the automobile and the radio. Farmers regularly visited nearby towns and cities. More importantly, the number of farms fell from 5.6 million in 1950 to 2.4 million in 1980, and the agricultural workforce from 12.4 million in 1910 to 8.5 million in 1940 and 2.75 million in 1970. By 1959 there were only 73,387 black sharecroppers left from the 270,296 of 1940. The migration of blacks to northern industrial cities was the most visible component of the postwar movement of millions from rural areas to urban centers to seek employment.

Local businesses, and often small towns themselves, with their schools and churches, withered and died. Farm families, like their urban counterparts, huddled around their radios (and, later, their televisions) in the evening. Farmers increasingly became businesspeople: Their success depended on keeping abreast of new technology and mustering the finances to afford these machines and chemicals (and the more extensive farms that mechanization made possible). Although farm values such as independence and hard work would survive, the gap in outlook between farmers and the rest of American society closed considerably.

In mines, as on farms, labor productivity expanded rapidly in the twentieth century as a result of technological innovation. Electricity allowed the mechanization of many below-surface functions (sparks from alternative energy sources risked causing explosions of underground gases). Only

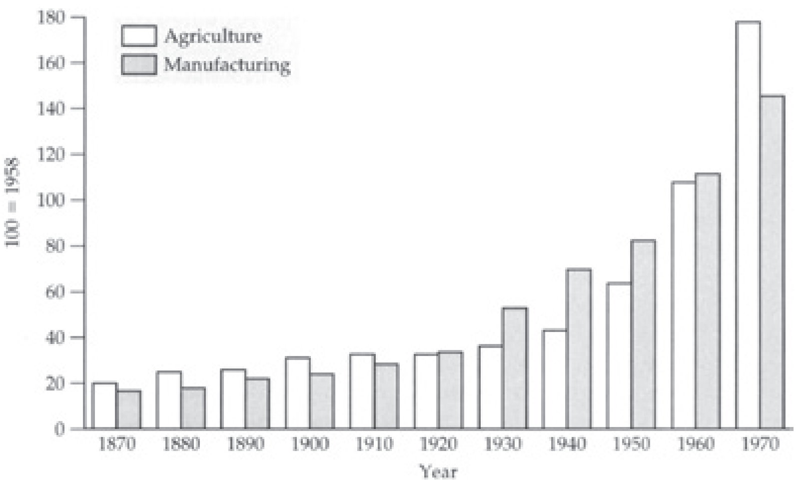

Figure 19.3 Productivity in agriculture and manufacturing. Note the sharp growth in productivity in the twentieth century, and especially in agriculture after 1945.

one-quarter of American coal was cut mechanically in 1890; virtually all of it was by 1950. The mining sector quickly adopted the advances in cutting tools discussed in Chapter 13. The tasks of loading materials onto wagons and hauling the wagons to the surface were also mechanized over the same time period.

The most significant changes would come after World War II. First, the continuous miner appeared in 1948. This vehicle was equipped with revolving cutters on the front that delivered coal to a haulage system of conveyors and shuttle cars. By 1969, this machine had tripled production per workday to 15.6 tons. An even simpler development, strip mining, was employed especially in the West where thick seams of coal existed near the surface. By blasting and then scraping the soil with mammoth earthmovers, coal could be exposed and easily trucked off. By the 1970s, earthmoving machines 20 stories high were removing 325 tons of 'overburden' at a time to reveal coal beneath.

The mining sector entered the postwar era with a problem similar to that of farmers. Despite the rapid increase of industrial output, American mining required less labor. In the case of coal, the increased use of petroleum as a fuel exacerbated this situation. Whereas in 1925 it required over half a million workers to extract 520 tons, by 1981 a workforce of only 208,000 mined 774 million tons of coal. Even militant trade unions could not prevent both the numbers and the incomes (relative to others) of coal miners from falling in such an environment.

Synthetic Fibers and Plastics

Another area of rapid development after World War II was synthetic materials. The expense of both research and production ensured that industrial research labs dominated research in this area. Nylon, displayed at the World's Fair in 1939, only hit the civilian market in full force after 1945. The stunning success of nylon stockings—there were virtual riots in stores in 1945—naturally spurred Du Pont and other chemical firms to develop other synthetic fibers. Nylon was neither as resilient nor as resistant to water as was desirable. Large research expenditures allowed the development of fibers superior in both respects. Orlon acrylic was introduced in 1948, and dacron polyester in 1949.

Orlon was used widely from the beginning in carpets and a range of other products. Polyester proved even more successful, becoming the most important synthetic in the US market. Indeed, polyester became more than just a product: It was a symbol of the times. Polyester trousers and jackets of the 1970s, inexpensive and wrinkle-free, were welcomed by a generation that wanted a more carefree lifestyle than that of its predecessors. Even though the polyester clothes of the 1960s and 1970s are now viewed as garish, even by those who wore them, polyester—often under other names—has remained a staple of the clothing business. Researchers have been at work in recent decades to give polyester a more natural look and feel.

Plastics played an even more significant role in the new consumer society. Important new plastics had been developed in the 1930s: among them urea-formaldehyde, acrylic (used to make Plexiglas in 1935), lucite, and vinyl (which allowed more grooves on phonograph records). Although the cost of plastic production fell through the 1930s, it remained more expensive than wood or metal and was thus used only for tasks that natural products performed poorly or not at all. During World War II, in the face of raw-material shortages, the government decreed that plastic should be used whenever possible. As a result, plastic output increased by six times in the decade after 1939. Plastic producers benefited from large-scale operation, which helped greatly to lower prices. Plastic production in tons was 1 percent of the output of steel in 1939 but surpassed steel after 1979 (Figure 19.4).

Figure 19.4 The National Bureau of Standards tests plastics for their ability to withstand weathering.

Research continued in the postwar period; its purpose was to develop a range of plastics, each suited to the characteristics of a particular set of products. This research naturally benefited from the enhanced scientific understanding of the properties of various molecules. Polystyrene was developed in England in 1933, but the complexities of production were only solved in 1940. After military use during the war (in radar especially), it found application in film, coated paper, molded articles, cable, bottles, and pipes. Output expanded by almost 50 percent per year for over a decade after 1945, and it became the first plastic to exceed one billion pounds in annual production. More generally, plastics producers developed markets in toys, flooring, tableware, luggage, furniture, shoes, and a host of other product lines. Thermoplastics of various types, which could be reheated and reset, came to dominance in the 1950s and allowed small companies—who might lack the resources to make plastic itself—to fashion plastics to serve whatever product line they wished to pursue. Tupperware, introduced from 1950, proved superior to natural products in many ways: It was light, airtight, easy to grip, and unbreakable. Tupperware marked a new acceptance of plastic in the domestic sphere.

As the number of fibers and plastics increased, it became increasingly difficult for these new products to find a market niche. Research costs rose as developers sought increasingly narrow characteristics. New synthetics had to compete with others already in the market. Du Pont found that Lycra spandex, Corfan artificial leather, and Qiana artificial silk did not sell as well as expected. When Du Pont introduced Kevlar in 1964, it was confident that a fiber five times stronger than steel would find a ready market. It did not. The company spent another $700 million in development costs before it achieved inroads in such areas as bulletproof jackets and airplane parts. By the end of the 1960s, chemical firms had begun to realize that they were unlikely to repeat the enormous profits associated with nylon. Research continues on both synthetic fibers and plastics, but the next chemical miracle will likely occur elsewhere.

Despite efforts to mimic natural products, plastics came to be perceived as unnatural in the postwar world. The ubiquity of plastics caused many to view modern reality itself as more malleable and impermanent. Plastics also affected human health: Scores of children suffocated in the first plastic dry cleaning bags before these were made less dangerous, and Teflon cookware was found to be toxic. There have been even more significant concerns about environmental impact: Plastic packaging has dramatically increased American production of garbage, and plastic biodegrades slowly if at all (and may release harmful chemicals when it does). The industry has responded from the 1980s by encouraging recycling, but this is as yet economically attractive only for some plastics. There have also been concerns regarding energy use, but plastics production usually requires less energy than alternative materials.

Medical Research

The tremendous advances in medical technology since 1945 have, like other innovations, shifted toward large-scale and increasingly government-financed research. Whereas government support of both healthcare and research was minimal before World War II, by the early 1990s the government financed 40 percent of health care costs and 60 percent of research expenditure. Some have questioned research goals that favor diseases that afflict men rather than women, represent the interests of doctors and researchers more than patients, or are more likely to produce a profit than solve a pressing medical or social problem. Even so, it is difficult to deny the tremendous advances in medical technology. In the 1980s and 1990s, political activists were successful in gaining increased funding for research on breast cancer and AIDS.

One sector of the medical field in which private research has remained dominant is pharmaceuticals. This research, of course, has roots long predating 1945. Although some natural drugs, such as ether, have been used for millennia, the first vaccination (for smallpox) appeared only in 1798, and the first anesthetic (chloroform) was used only in 1847. The modern era of medical drugs began in the late nineteenth century. German chemical firms started then to undertake pharmaceutical research and production. There is a similarity between dyes (the primary product of chemical firms of the time) and drugs, in that the former must adhere to the cloth while being impervious to cleaning substances, and the latter must attack a particular bacteria or virus while not harming the person under treatment. The work then (and, to a lesser extent, now) was mostly trial and error, for chemical reactions in the body were poorly understood. The acceptance of bacterial theory in the 1880s—and the success of quinine against malaria, mercury against syphilis, and vaccines for such diseases as rabies (developed by Louis Pasteur in the 1880s), diphtheria (1891), and tuberculosis (early 1900s)—gave a tremendous boost to drug research. Many countries established public health authorities in the late nineteenth century, and these provided a significant source of demand for vaccines and other drugs.

American companies followed the German leaders early in the century, with Parke-Davis opening the first laboratory in 1902. The appearance of the tablet-making machine in the 1890s made possible the name-brand drug, which widely replaced the preparation of medications by the pharmacist. World War I opened up a sizeable military market; then the peace treaty after the war gave American firms access to German patents. In the interwar period, many companies expanded their research effort. Squibb filed one patent in 1920, 21 in 1930, and 164 in 1940. After a further boost from World War II, American drug companies maintained a dominant role in many areas of drug research in the postwar era.

The increased research produced notable results. The antiseptic mercurochrome was the primary American discovery of the 1920s. Canadian researchers at the University of Toronto isolated insulin in 1923, and the Englishman Alexander Fleming in London isolated penicillin in 1922. During World War II, the United States Army drew university researchers and twenty drug companies together to develop methods of mass-producing penicillin (achieved from 1944); Pfizer and other companies thus established an extensive research infrastructure. In the 1930s, German and French dye makers discovered sulphanilamide, which was found to be effective against a range of bacteria. This led to a series of sulfa drugs. Others in the 1930s synthesized vitamins and developed antihistamines against allergic reactions (Figure 19.5).

These successes spurred a tremendous postwar research effort. Penicillin worked well on syphilis and open wounds but provided no help against tuberculosis or e.coli bacteria. Numerous antibiotics—organic chemicals that combat undesirable microorganisms—were produced in the early postwar years. Antibiotics and penicillin were hailed as wonder drugs because they proved effective against a wide range of diseases caused by microorganisms, including gonorrhea, tuberculosis, and bacterial pneumonia. Prescription-writing became a central activity of the medical profession; a law of 1951 insisted that a broad range of pharmaceuticals would only be available by prescription. Patients came to pressure doctors for prescriptions, even when suffering from a viral infection against which antibiotics had no effect. Fears of over-prescription caused the United States government to insist on clinical trials from 1962: Pharmaceutical companies had to show that a particular drug had an impact on a specific disease. While clinical trials might prevent the marketing of drugs with no known effect on disease (though some claim that half of the medications approved had limited or no effect), they could not prevent doctors from prescribing approved drugs for entirely different diseases on which the drug might have no impact. There were concerns from the beginning that bacteria were evolving

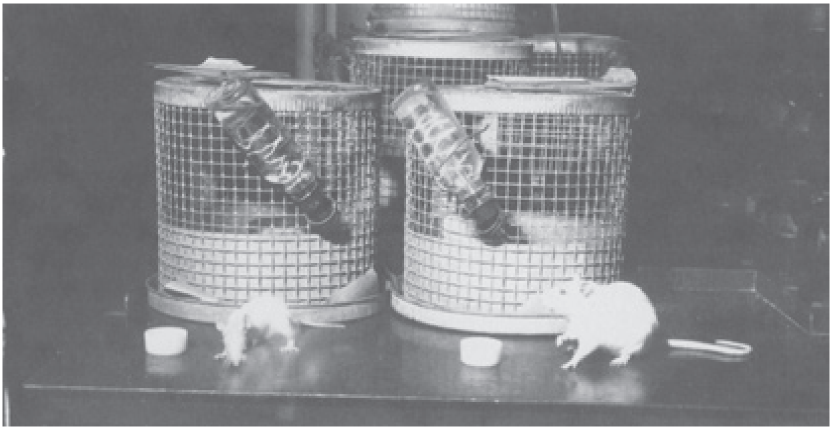

Figure 19.5 Parke-Davis labs, 1943: An early experiment with vitamins. The mouse on the left had the same diet as that on the right, except for the absence of riboflavin.

Credit: *Courtesy of the Library of Congress Prints and Photographs Division.*

to become resistant to antibiotics as a result of the over-prescription of antibiotics; these fears were widespread by the 1990s. Some European countries, as a result, regulate the prescription practice of doctors but this idea has not gained extensive support in North America. Part of the problem is that drug companies encourage doctors to prescribe particular drugs for ailments other than those for which the drug has been approved.

Before the 1970s, when advances in biochemistry became important, researchers often relied on 'random screening' where new compounds were tested over a wide range of possible effects—new diuretics and vasodilators were found in this way. In the 1950s, the first psychotropic drugs for altering moods were introduced (the most famous, Valium, came in the early 1960s). Also in the early 1950s, Jonas Salk and others developed the polio vaccine, which has since saved countless millions from this crippling disease.

Most drugs, however, have some sort of side effects, and we should be careful not to casually glorify the advance in pharmaceuticals. Hundreds of thousands of people are hospitalized every year because of adverse reactions to drugs, or dependence on tranquilizers. After the horror of thalidomide, which produced severe birth defects (such as missing limbs) in thousands of European children between 1959 and 1962, the process for approval of new drugs was tightened to assess possible side effects better. The government review process for new drugs was 'streamlined' during the 1980s so that new drugs could reach the market more quickly. While proponents argue that this increases the rate of innovation, critics maintain that we are all guinea pigs as a result.

University-based advances in biological understanding would revolutionize the drug industry from the 1970s. Whereas previously drug researchers had looked for drugs that would have a desirable effect on, say, blood pressure, they now knew which enzymes affected blood pressure and could use both scientific knowledge of chemical reactions and laboratory experiments in developing drugs that would affect those enzymes. More centrally, biotechnology itself, which can be defined in terms of manipulating the characteristics of cells so that these produce particular proteins, can be said to have emerged with a method developed by Cohen and Boyer in 1973. While the human body relies on half a million different proteins, research has focused on a critical handful (such as insulin and human growth hormone). Notably, biotechnology can lead to both improved production of existing drugs and the development of new drugs. New drugs have usually been developed by small start-up companies composed mostly of university-based researchers. But the large drug companies have successfully bought out or partnered with these, for they bring essential expertise in mass marketing and mass production, not to mention extensive monetary resources and experience with the drug trial process. The United States has been the world leader in biotechnology, in large part due to the strength of its university research, the ease with which biotechnology can be patented in the United States, and the close links that have long existed between universities and drug companies.

The postwar pharmaceutical development with the most significant social impact was the birth control pill. Prevailing social attitudes had been a barrier to research for decades. In the early decades of the twentieth century, it was illegal to sell or advertise birth control devices. While condoms were not difficult to obtain, diaphragms (invented in the 1830s, shortly after Goodyear developed vulcanized rubber) and cervical caps had to be smuggled into the country. Because the medical profession refused to sanction birth control, these devices were often misused (diaphragms were left in for days, for example). Resulting infections only strengthened the opposition of doctors to birth control. Only in 1930 did it become legal to ship birth control devices into the United States—but just for the prevention of disease.

Numerous firms then entered the business, and within a few years, Americans were spending hundreds of millions of dollars on birth control. Later in that decade, the American Medical Association finally recognized the arguments of Margaret Sanger and others who had been campaigning for free access to birth control for decades and began to lobby state and federal governments for the right to disseminate birth control information and devices.

Drug researchers soon entered the fray to develop a birth control pill. Perhaps because they were virtually all men, they focused entirely on controlling female rather than male fertility. Although the male reproductive system is much simpler, many researchers argue that periodic female fertility is easier to manage than constant male fertility. Others would claim that since women bear most of the costs of pregnancy, they are more likely to take a responsible attitude to birth control. In any case, some 13 distinct methods of female contraception were developed in the last half of the twentieth century, but there has been no new male contraceptive since the condom (though some researchers have explored whether injections of testosterone might serve this purpose). The key to the birth control pill was the discovery that the natural hormone progesterone prevented ovulation. Then, years were spent developing progestogen, a synthetic analog to progesterone that could artificially prevent ovulation. The pill containing both progestogen and estrogen was invented in 1951, but it was not marketed on a large scale until the 1960s. This pill arrests ovulation completely by mimicking the body's behavior during pregnancy. The pill was a significant advance in birth control technology and is rightly hailed as a major (although far from the only) factor in the sexual revolution of the 1960s. Though many involved in developing the pill were interested primarily in population control, the pill arguably had its most significant effect socially, giving women a sense of control over their bodies and changing the way they interacted with families, partners, and religious institutions.

The pill was not a perfect solution to the birth control problem. Many women cannot take it because of severe side effects; pill use has been linked to cancer; and those who are on the pill for many years have some difficulty in conceiving later in life. Many question the wisdom of fooling around with a woman's natural biological rhythms. However, modern women, who tend to menstruate earlier, reach menopause later, and have fewer children than did women a century ago, may have as many as ten times as many menstrual cycles in their lives. Some, at least, find their normal cycle discomforting and find that the pill eases their hormonal fluctuations.

Drugs are far from the only area in which medical technology has advanced. Tools for diagnosis have seen considerable development. X-ray devices were first used in 1895, shortly after the accidental discovery of X rays by Roentgen while investigating the properties of mineral salts (he refused to patent the device), and after various improvements had become commonplace by the 1930s. They would be linked to televisions in the 1950s and digitized in the 1970s. The CT (computed tomography) scanner uses data from X rays to produce computer-generated three-dimensional images; it was developed in Britain in 1973, but GE soon became a leader in CT technology. Ultrasound was an offshoot of World War II research on sonar and became common shortly after the war. Magnetic resonance imaging (MRI) was developed in 1982: it relies on radio waves and magnetic fields, rather than radiation, to generate images, and is capable of capturing images of soft tissues. MRI technology grew out of basic scientific research and depended on both better superconductors and better magnets. As with the CT scanner, sophisticated algorithms are necessary to interpret the data: Firms with previous CT experience dominated MRI technology (Figure 19.6).

As early as the eighteenth century, it was recognized that the human body generated electricity, but only in the twentieth century were techniques for measuring human electrical wave generation introduced. The first electrocardiogram for measuring heart activity appeared in 1903 and had achieved a

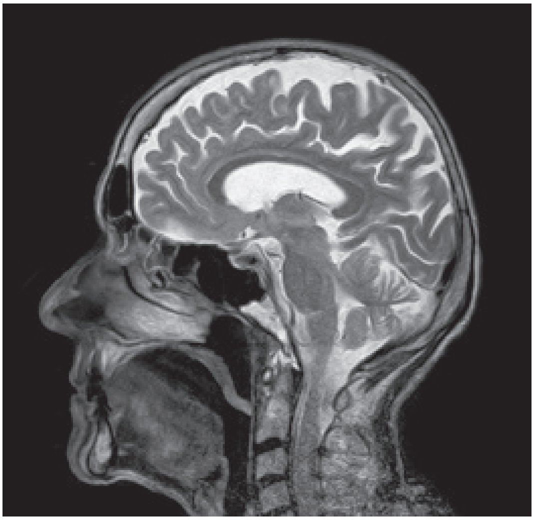

Figure 19.6 An MRI image of the human head.

Credit: *Wikimedia, GNU Free Documentation License.*

reasonably modern form by 1912. The electroencephalogram for measuring brain activity followed. Anyone who has visited a modern hospital will be aware of the mass of electronic gadgetry now used for diagnosis.

Nuclear medicine advanced rapidly after 1945. By the 1990s, a third of the thirty million Americans hospitalized each year experienced it in some form. Bone scans can detect cancer more than a year in advance of X rays. Brain tumors are often treated with a narrow beam of radiation, to protect the surrounding tissue (ultrasound can also now be used to remove tumors). And, of course, those with other cancers are also commonly treated with radiation.

Techniques for more invasive diagnosis have also improved. Fiber optics revolutionized endoscopy; previous tubes were uncomfortable and offered a limited view of internal organs. Building on advances in both glass manufacture and physics, the first medical use of fiber optics occurred in 1957 at the University of Michigan. The device was commercialized in 1961. Academic researchers also developed an endoscope with a computer chip at the end to transmit data; this was commercialized in 1981.

Artificial devices to aid or replace body parts that cannot perform their functions were developed. Artificial joints and limbs have significantly increased the quality of life for millions. The first dialysis machine, to treat kidney failure, appeared in 1913, and the first artificial kidney in 1940. Other major organs, though, have been more difficult to duplicate. The pacemaker has been useful in helping weak hearts. Researchers in the 1960s expected that a few years and a few million dollars would yield a mass-produced artificial heart. Hundreds of millions of dollars and countless experiments later, the devices are still costly and relatively ineffective. Indeed, research of all sorts in both the areas of heart disease and (most types of) cancer have had little effect on death rates over the last quarter-century.

It is important to recognize both the achievements of medical research and its limitations. In particular, we should note that advances in nutrition and public hygiene have also had a significant impact on our health and longevity. Average life expectancy in the United States was 54.1 years in 1920, 62.9 in 1940, 68.2 in 1950, 73.7 in 1980, and 77 in 2000. Certainly, throughout the nineteenth century, these areas of improvement were the dominant source of lower mortality rates, and many would argue that they were more important than medical advances even in the twentieth century. Declining birthrates have also had a significant impact on the health of women and they may also have improved the care received by the remaining children.

Finally, we should note how changes in technology have transformed the roles of doctors and hospitals. As diagnostic equipment improved, and the human body came to be viewed as a machine capable of repair, the prestige of doctors rose. One early result was the replacement of midwives at childbirth—though at first mortality rates actually rose as a result. Hospitals, before 1870, were viewed by patients as warehouses for the dying—or even death traps—in which they were cut off from friends and families. With the germ theory of disease and the development of anesthetics, hospitals came to be viewed as places where people might actually go to get better. Diagnostic laboratories were established in hospitals in the 1880s. The first American nursing school was founded in 1873, and by the 1920s one-quarter of hospitals had a nursing school. Only 15 percent of American doctors were affiliated with a hospital as late as 1900, but 83 percent were by 1933.

The medical profession thus gained unprecedented prestige in the first half of the twentieth century. The education and self-image of doctors did encourage the rapid diffusion of new medical technology. However, patients came over time to rebel against the impersonal, mechanistic nature of the modern doctor-patient relationship. The postwar world has been one in which respect for most professions has diminished, and doctors have not been immune from this. Polls show that three-quarters of the people questioned had confidence in doctors in the 1960s; less than a third did in the 1980s (similar results can be found for medical research). Many now turn to the internet first for medical advice. While much has been gained in the last century, something important—the personal touch—has all too often been lost. Nursing has suffered even more in some ways: Whereas medical researchers often designed instruments for skilled use by doctors, they often mechanized nursing tasks and thus decreased certain skill and nurturing components of nursing.

As health care became big business, and ever-more sophisticated technologies were developed to combat particular ailments, the cost to society of health care steadily rose. The United States has for decades devoted a much higher percentage of its national income to healthcare than any other nation (without achieving significantly better life expectancy than in most other developed countries). Still, rising healthcare costs became a public policy concern worldwide. Many studies have pointed to specific tests and procedures that serve little or no purpose (e.g. it has been suggested that annual PAP smears do not reduce the risk of cervical cancer significantly over having one test every three years). Some tests may generate more costs through inevitable false results than the good that may come from correct diagnoses; some tests screen for ailments that cannot be cured.

Beyond these potential cost savings, society will have to make some tough decisions. When we design traffic interchanges and highways, we implicitly put a value on human life by deciding on the standard of construction (divided highway or not; overpass versus traffic lights). We may need to do the same in the medical field and target our research on cures that society can afford.

Note

1 Light is emitted by atoms when these are excited by electricity, heat, light, or chemical reaction. In lasers, multiple atoms are induced to generate a self-reinforcing flow of light with a single wavelength. Einstein suggested this possibility, but it was first achieved only in 1958. Its potential was but dimly appreciated at the time. Lasers are now used as welding and cutting tools, in fiber optics, in compact discs and DVDs, in various medical procedures, in fusion research, in military targeting and weapons research, and across a wide range of scientific research.

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20 Our Digital Age

Historians might well say that the computer has ushered in a third industrialization. Whereas the first (based on steam) and the second (built on electrical and petroleum power) revolutionized manufacturing, transportation, and communication, this third wave of technology radically transformed access to information and the operation of machines. Its impact may be as large as any earlier technological breakthrough, affecting work, play, learning, and social life in still undetermined ways. So important has the computer and its related technologies become to American life in the early twenty-first century that we must devote a chapter to it. Its evolution is marked by a number of transformations: The progressive miniaturization along with escalating power of digital technology; repeated contests over technological standards; a shift from government and business to personal applications; and a gradual move from innovations in hardware to software and computer services.

Data Processing and the Origins of the Digital Computer

The modern computer has its roots in the age of steam, in the dreams of the British mathematician Charles Babbage (1791–1871). In his hopes of correcting hand-calculated mathematical tables used in astronomy and navigation, Babbage conceived of a complex steam-driven machine in 1812. His Difference Engine consisted of thousands of gears, levers, and other common machine parts, which, when moved in specified patterns, performed complex calculations. Babbage's design contained all the elements of the modern computer (data input and storage, a program of instructions, a processing unit, and output device). However, neither this machine nor his later Analytical Engine were successfully built because of cost and the difficulty of constructing machines of such exacting specifications.

However, by the end of the nineteenth century, governments and large companies found that they needed to store, retrieve, and compute large quantities of data. For example, the process of manually counting and sorting the census information of 50 million Americans for the 1880 census was incomplete after five years. In an effort to speed up the process, and make the 1890 census more useful, the Census Bureau eagerly accepted the inventions of Herman Hollerith, a young former employee. Hollerith introduced a system of recording alphanumeric data by punching holes in cards. When the cards were fed into his machinery, pins passed over the punched holes and touched a metal surface below, making electrical contacts that registered the data. In 1896, Hollerith founded the Tabulating Machine Company and sold his data processing equipment to large insurance companies, department stores, and railroads. Hollerith's company became International Business Machines (IBM) in 1924 and manufactured a wide range of adding and other calculating machines. Many of these devices were electrically powered, but the calculations had to be performed mechanically by hand pressing keys representing digits. These business machines were necessarily slow and subject to human error.

Only the demands of university and government research led to more complex calculating machines. Beginning in 1927, the MIT engineer, Vannevar Bush (1890–1974), picked up where Babbage left off. His Differential Analyzer first used gears, pulleys, cams, and rods to mechanically represent numbers and the various functions in the equations that were used in electrical power and astronomical calculations. This analog computer was complex and required perfect construction. An electrical version of Bush's mechanical analog computer followed (in which variations in voltage represented data); it was faster, but not always as accurate.

Because vacuum tubes were improved during the interwar period, an electronic computer became a possible replacement for the analog calculator. Electronic tubes were valves that could represent '0' when closed and '1' when opened (switching at a hundred thousand pulses a second). The speed of this electronic valve made possible a binary (or digital) system of data processing when numbers and other data could be represented by various combinations of the digits 1 and 0, organized into eight bits of code (or one byte).

The first digital computers appeared during World War II. With financing from the British military, the Colossus broke German code and the ENIAC (of J. Presper Eckert and John Mauchly of the University of Pennsylvania) was built to improve gun ballistics. Unlike early digital computers, the ENIAC was programmable, and after the war in 1946 it was quickly adopted by nuclear physicists. It was bulky (weighing 50 tons and taking up 3,000 cubic feet of space) and complex (using 18,000 vacuum tubes), and costly (consuming 160 kilowatts of electricity). Still, the ENIAC was reliable and could solve a problem in two hours that required one hundred mathematicians with mechanical calculators a year to complete. The major drawback was that programming these mammoth machines was a skilled and time-consuming task, demanding days of rewiring. Many of the earliest programmers were women mathematicians. Especially well known was Grace Murray Hopper, who worked on the UNIVAC and was a pioneer in the development of the COBOL programming language.

Soon computers shifted from exclusive military to civilian uses, beginning in 1951 with the UNIVAC, developed by Eckert and Mauchly at the Rand Corporation. This computer's electronic memory unit stored programs and data and was used by the US government to tabulate the census. The Rand Corporation faced competition when IBM introduced the '650' in 1954 for use in business. More compact than the UNIVAC, the '650' won managers' loyalty with its large sales and service staff, and knowledge of business needs. Most IBM computers were rented. By the late 1950s, IBM controlled about 70 percent of the computer market, a position that it long maintained thanks to the development in 1964 of new and improved 'mainframe' computers especially the System/360. This computer dominated the business market with its ability to transfer programs and data between machines and its adaptability to a variety of uses even though its most advanced version had only 8 megabytes of main memory (Figure 20.1).

Into the 1960s, most computers remained big, but still fragile, machines that required storage in air-conditioned rooms to prevent the vacuum tubes from overheating. White-coated technicians fed them with punched cards and read the numbers and code that the machines spit out on reams of perforated paper.

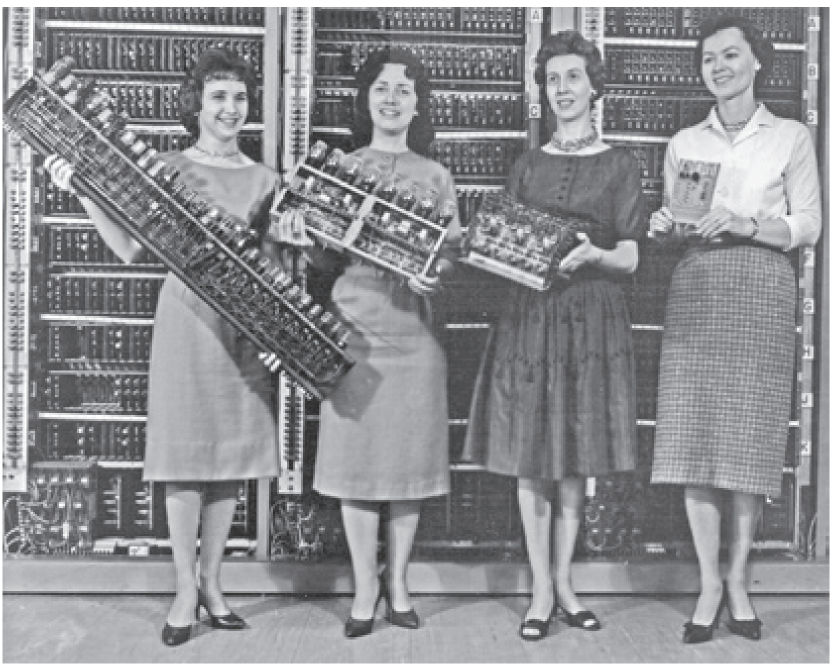

Figure 20.1 Women programmers holding components from a series of army computers beginning with the oldest, the 1945 ENIAC on the left and the 1962 BRLESC-I computer on the right. Notice the miniaturization.

Credit: *US Army.*

Punched cards became the symbol of the computer's seeming power to reduce people to abstract data. Student radicals in the 1960s, protesting the dominance of technology and big bureaucracies, found it ironic that the phrase "do not fold, spindle or mutilate" was printed on IBM computer cards (because cards thus altered could not be read by the computer), while those very cards used by the university seemed to dehumanize or 'mutilate' students and others. By 1969, tax and police agencies were sharing personal information on computers. Credit research companies already had data on 20 million Americans in their electronic databases. In movies such as *2001: A Space Odyssey*, powerful computers went mad. The computer seemed mysterious and distant: Locked up in large, climate-controlled rooms, with no heart, and run by hyper-efficient nerds. This was not to last.

Transistors and Chips: New Personal Devices and the Miniaturized Computer

From the mid-1950s, the transistor and its descendants transformed not only old analog technologies like the radio, phonograph recording, and the camera, but also miniaturized ever-more powerful computers, leading to the PC. Replacing the comparatively large, fragile, and often unreliable electronic vacuum tube, the transistor was an electronic valve and amplifier based on silicon, eliminating the need of electrons passing across a vacuum instead of solid materials. This semiconductor was introduced in 1948 by Bell Labs led by John Bardeen, Walter Brattain, and William Shockley. The day of the heroic individual inventor was long over. In fact, the American military financed much of the early development of the transistor, initially for radar. Compared to the vacuum tube, transistors were smaller and more stable, neither burning out or overheating. Transistors also used far less energy and were faster.

In 1958, the next stage of innovation began when the first integrated circuit—two and ultimately many more semiconductors on one silicon crystal—was invented by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor. The integrated circuit miniaturized many circuits, involving transistors and related components. The integrated circuit led to a vast simplification of many electronic devices, especially TVs, radios, and stereo record players. An especially important new product was the hand-held electronic calculator (on the market in 1971).

In 1971, Intel replaced integrated circuit boards by the still smaller and yet far more powerful computer chip or microprocessor onto which thousands and eventually millions of transistors were imprinted. Gordon Moore, who co-founded Intel, famously proposed what now is known as 'Moore's Law'—that the number of transistors per chip will double every 18 months.

With the introduction of these solid state technologies came the transformation of the phonograph, camera, and other devices. Perhaps not realizing the commercial potential of the transistor in consumer electronics, AT&T, Bell

Lab's parent company, licensed use of the transistor to others, especially Sony of Japan. As a result, newer and smaller companies installed the transistor into many electronic products. Included were the transistor radio (introduced by Sony in 1957) that was widely adapted by teens to listen to their own music (especially the newly-minted Rock 'n' Roll) away from annoyed parents. Hand-held transistor radios couldn't offer the sound quality of home stereos, but they were portable.

In 1963, Phillips introduced the next stage of transistorized audio, the cassette player. This device replaced the magnetic analog tape recorders that had been invented in the 1930s but were so bulky and cumbersome to play with their reel-to-reel design that they were used mostly by professionals. By contrast, the cassette tape (likewise analog) could be easily slipped into its player, offering an appealing alternative to the vinyl record with its requisite stylus and turntable. From the 1970s, the cassette tape player was adapted to cars and boom boxes, a larger, louder, big bass radio and cassette player. In 1980, Sony offered still another type of cassette, the Walkman. This was a retro/revolutionary device that resurrected the earphones of early radios while simultaneously mobilizing (and isolating) the listener. The cassette also revived another old idea—recordability—that the phonograph had abandoned in the late 1890s. This had interesting implications in the realm of intellectual property, since personal recordability also allowed ordinary consumers to circumvent copyright. The video cassette recorder (VCR) came in 1974 and camcorder in 1983 (see Chapter 17), offering consumers a means to personalize their TV watching and even to make their own video recordings.

All of these media devices recorded and played by transmitting sound and light analogically. However, a digital revolution soon followed, taking full advantage of microprocessor technology. This began with the replacement of the cassette with the Compact Disc (CD), first introduced commercially by Phillips in 1983. In a CD recording, the amplitude of the sound wave is no longer copied analogically but is transformed into a digital signal thousands of times per second. A laser inscribes a spiral of tiny pits alternating with empty spots onto the disc. A laser in the disc player reflects back light onto a sensor where there are no pits (read as ones) while the laser's light is diffused at the pitted areas (read as zeros). These digital signals are then converted into analog electronic signals and then into sound waves (and, in the case of the DVD which followed in 1996, video as well).

Connoisseurs of music greeted the CD with concern about the information lost during digitization. Yet, the sound quality of CDs proved quite good (who could tell the difference when the sound wave was sampled 50,000 times a second?). Moreover, the CD was free of the cassette's background noise and less subject to wear; duplication was also far faster than cassette recording. By 1991, audio stores abruptly abandoned both vinyl and tape. The digital CD victory, though, was also short-lived. By 1996 sales had stalled with the MP-3 recording that no longer requires a physical carrier (like a record, cassette, or CD), but is transmitted over the Internet (more later). This allowed hundreds of hours of music to be stored and accessed instantly.

An equally important adoption of digital technology was in photography, replacing more than a century of capturing images chemically. Tiny sensors, called charge-coupled devices or CCDs, invented by William Boyle and George Smith at Bell Labs in 1969, measure light intensities in tiny discrete points called 'pixels' that are transformed into electrical charges. These pixels can be stored as digital code when sampled, creating in time high-resolution images transferred electronically. And though this technology was first quite expensive, confined to astronomy, medicine, and the military, advances in data compression and storage allowed for the introduction of the personal digital camera in 1990 in the US. It quickly replaced the chemical photographs of traditional roll film cameras. Digital cameras eliminated the wait and waste of conventional film processing; they also allowed the taking of hundreds of pictures without reloading film.

The key innovations occurred in media devices, but another product of the electronic era was the microwave oven. An offshoot of radar technology from World War II, the microwave oven became a practical home kitchen appliance by 1967. The oven heats food evenly with high-frequency electromagnetic waves rather than from the outside in as in conventional ovens. The result is much faster cooking. Microwave ovens were quickly adopted, especially in households where all adults work outside the home (later with digital controls added). The microwave has made meal creation much easier, though some worry not only that taste and sometimes nutrition are sacrificed, but also that people come to place less importance on good cooking and eating. This array of new consumer devices, from the transistor radio and hand-held calculator to the CD, digital camera, and microwave oven have transformed the way we listen, see, eat, and much else.

But the advent of transistor and digital technology most dramatically transformed the computer and all the devices that surrounded and came from it. The transistorized computer first appeared in 1953 and was brought to market by Philco in 1957 for scientific applications. In 1959, IBM replaced its vacuum tube '709' with the transistorized '7090' that was six times faster, and half as expensive to rent as the older model. This second generation of digital computers were improved with magnetic-core memory (comprised of tiny magnetic rings threaded with wires), magnetic tape readers (partially replacing cards), and disk drives that could store data. Moreover, these new machines read higher computer languages that were written in ordinary language and math greatly easing programming. FORTRAN ('formula translation') and COBOL ('common business-oriented language') were especially important computer languages to a new group of skilled workers—computer programmers (Figure 20.2).

The next generation of computers came in 1965 with Digital Equipment Corporation's minicomputer, the PDP-8 (1965), based on the integrated circuit. It was only the size of a small refrigerator and was much faster than

Figure 20.2 Early transistors used in the IBM 1401 (1959). In addition to the transistor's small size, the transistor did not need either a vacuum or a long warmup period.

Credit: *Wikimedia Commons, Creative Commons, Marcin Wichary photographer.*

earlier computers. A final generation of computers came in 1975 with the microprocessor. By radically miniaturizing circuits and thus putting most computer functions on a single chip, the personal computer (PC) became possible. The first successful PC was H. Edward Roberts's Altair 8800 (based on Intel's 8080 microprocessor). It was really a toy for hobbyists, promoted through *Popular Electronics* in 1975: it lacked a monitor, and used teletype keyboards. Nonetheless, the Altair convinced many that computers could be used by ordinary people. Only two years later Commodore Business Machines introduced a more useful PC that included a monitor, keyboard, and cassette player (for running programs on tape). It had the ability to produce graphics and spreadsheets (Figure 20.3).

Of more lasting success was the Apple II of 1977 with its beige plastic case, cassette drive, keyboard, and monitor. Easy to use, the Apple II established the reputation of its California-based developers, twenty-two-year-old Steven Jobs and twenty-seven-year-old Stephen G. Wozniak. In 1978, Apple greatly improved its system with the introduction of a 5 1/4 inch floppy disk and drive, which improved on the cassette tape by allowing random access to data.

Despite this breakthrough, it held only 113 kilobytes of data, and cost nearly five hundred dollars. Only in 1981 did the giant in computers, IBM, realize the need to enter the market with its first PC, a modest machine with access to no more than 640 kilobytes of memory.

As important as the PC was the development of new software—easy-to-use operating systems, and word and data processing packages. In 1981, twenty-six-year-old William Gates developed the Microsoft disk operating system (MS-DOS) for IBM. Seattle-based Bill Gates and schoolmate friend, Paul Allen, were already veteran software writers. In 1975, while undergraduates at Harvard, they created a new version of BASIC, a programming language, for the Altair computer, eliminating the need to write programs with machine code (or the relatively difficult FORTRAN or COBOL). Gates and Allen, however, refused to tie their fates to the company that made Altair (MITS), and retained the rights to their software. Subsequently, Gates became a free-lance software writer, and moved his new Microsoft Company to the Seattle area in 1978. When hired by IBM to write a new operating system, Gates bought a program from Seattle Computers and its improved version became MS-DOS, a text-based, 16–bit operating system. Gates then won from IBM the legal right to market MS-DOS separately from IBM's PCs. Gates proceeded to make a fortune from the licensing of MS-DOS, selling two million copies by 1984, and making it the dominant operating system within a few years. IBM PC 'clones' or IBM compatibles (beginning with Compaq in 1983) found substitutes for IBM's copyrighted basic input-output system (BIOS) and,

Figure 20.3 This MITS Altair 8800 was promoted to hobbyists through *Popular Electronics* (1975). Although primitive, this machine launched the age of the popular personal computer.

Credit: *Wikimedia Commons, Creative Commons, photo by Cromemco.*

along with IBM, flooded the market with computers equipped with MS-DOS. In the original collaboration of 1981, the real winner was Microsoft, not IBM. IBM and its clones also drew on Intel and other chip makers as well as other suppliers for essential components, making for a less centralized technology than some of its predecessors. Microsoft also developed business software packages (including Word and Excel) that saved much time over manual programming. The PC became a computer that no longer required skilled technicians.

Many computer enthusiasts preferred the Apple, and especially the much-improved Macintosh computer of 1984. This machine provided a 'graphic interface' that allowed commands to be executed by pointing and clicking with a 'mouse' at pictures or 'icons' on the monitor screen. The Macintosh also had a sound system, and a high-resolution black-and-white monitor. However, the Jobs/Wozniak team soon broke up and, despite Apple's cultivation of loyal 'Mac' users and the introduction of their computers to many schools, the links of IBM (and its clones) with Microsoft proved to be too dominant in the market for Apple to overcome.

Most importantly, in 1984 Microsoft developed a new operating system, Windows, that shared much with the Macintosh. Microsoft's Windows was an extension of the MS-DOS operating system, but it greatly simplified handling tasks by substituting mouse-activated pictures or icons for complex typed instructions. The now-familiar mouse had been invented only a year earlier. Windows also could run several applications at the same time and allowed the transfer of data from one application to another. Even more impressive was Windows 3.0, introduced in 1990. Building on earlier successes, Windows 95 appeared in 1995, selling seven million copies in two months.

Making the PC User-Friendly

Beyond these basic innovations, improvements in data storage and transfer, as well as new input and output devices, greatly expanded the capacity and use of the computer. As we have seen, the magnetic cassette tape system used to store data was replaced in 1976 by the faster external disk drive that allowed fast random access to information. This 'floppy' disk was a flexible, magnetic 5 1/4 inch card, and with a capacity of 320 kilobytes could hold the data of 3,054 IBM punch cards. The floppy drive made it possible to easily store and transfer data on a small desktop machine. Sony's hard-cased (no longer floppy) disc of 3½ inches was introduced in 1981. It was not only smaller but had greater capacity, within a few years reaching 1.44 megabytes.

Even more important was Seagate's magnetic internal hard drive (1980). This rigid metal disk coated with a thin layer of magnetic material had the then-extraordinary capacity to store five megabytes of data. Following quickly was the CD-ROM, introduced by Sony in 1984. At first, the CD-ROM disk held 550 megabytes of prerecorded data (compared to the 1.44 megabytes available on floppy disks). Based on the laser technology used in CD players, the CD-ROM greatly increased the size of programs. Word processing programs, for example, ballooned in size to accommodate more features and the special demands of Windows. The CD-ROM drive provided access to images, and far more sophisticated graphics in games. By 1985, whole encyclopedias could be stored on a single CD; the first was *Grolier's Electronic Encyclopedia*, a nine-million-word reference book that took up only 12 percent of the available space on the CD. Even the authoritative Encyclopedia Britannia was obliged to replace its venerable reference books with a two-CD set. In 1992, a commercial CD recorder (or 'burner') became available at $11,000. By 1995, the cost was 'only' $995—but, as was true of so many computer innovations, the price dropped sharply thereafter.

Paralleling the dramatic improvements in input and storage devices were advances in peripheral technology. The advance in printers was extraordinary: Impact printers (operating like old-fashioned electric typewriters) produced high-quality print but were slow and expensive. The dot-matrix printer was cheaper but yielded relatively poor-quality characters. By the late 1980s, laser-jet printers were available, overcoming the speed and quality problems of their predecessors. As recently as 1987, laser-jet printers retailed for $2,600, but they also decreased sharply in price over the next decade, becoming standard in personal computing.

The next improvement was the scanner. It was long preceded by telephotography in which radio or phone signals could be transferred over wire to reproduce images. This was a slow process mostly confined to telegraph offices from the late 1920s. Modern scanners are based on the same technology as the digital camera. This technology, when applied to the computer scanner, was first available in the mid-80s, but cost $40,000, and was unable to accurately reproduce much printed material. Improvements in the 1990s made the scanner a common tool for reproducing images that could be transferred from computer to computer via disks and later via the internet.

Underlying all of these improvements were the seemingly unending advances of computer speed with ever more powerful microprocessors or chips as Intel moved from its 16-bit 8088 of 1979 (with 29,000 transistors) to the Pentium microprocessor of 1993 (with 3.1 million transistors). This improvement closely followed the prediction of 'Moore's Law'. Moreover the 18–megabyte hard drive on the PC of 1983 became a 10–gigabyte shortage unit by 1993 (a thousand-fold increase in a decade), and, by the early 2000s, 100 or more 'gigs' of digital storage was common and advanced models soon had three terabytes (3,072 gigabytes). The capacity of random access memory (RAM) cards also increased dramatically, rising from a standard of four megabytes of RAM in the early 1990s to 256 and even 512 megabytes of RAM by 2003, escalating to three gigabytes on high-end PCs by 2017.

As PCs became more powerful, they also got smaller and more mobile. Until 2000, most PCs were desktop devices with separate monitors, keyboards, and computer processing units (CPUs). The first portable PC appeared in 1981 with Epson's HX-20, but its screen could show only four lines of text. Gradually improvements (including the touchpad, improved batteries, and

LCD screens) made the laptop an alternative to the desktop. Tablet computers followed a similar course, becoming a common addition to the household after 2005 when touchscreen tablets replaced earlier models operated by styluses. Again Apple led the way with its iPad of 2010 followed quickly by Android-operated tablets.

From the mid-80s, software for word processing, spreadsheet, and other programs was changing every 18 months. The number of computers in use in the United States rose from ten million to 45 million between 1983 and 1988, as they became more 'user-friendly.' Computers became the tools for many common business and entertainment activities—including document production, calculation, information retrieval, games, music, and movies. By 2016, a computer device was in the homes of 85 percent of Americans. All this was accomplished by a number of component companies ranging from Intel to Microsoft. No longer was there a dominant integrated producer like IBM had been in the 1950s and 1960s.

Origins of the Internet

By far the most important transformation of the personal computer has been the development of the Internet, a network of digital applications including e-mail and the web. It marks the shift from the primacy of hardware innovation to software and computer services. Despite its use today for accessing entertainment, knowledge, and commerce, its origins are in the technical worlds of engineers and the military. By the late 1950s, MIT scientists had found that they could link to giant mainframe computers via telephone lines from dispersed work stations, creating the possibility of 'time sharing' on the mainframe's processor. An essential innovation making this possible was the modem, whose name is an acronym that expresses its two functions: Modulating digitized information for transmission over phone lines and *dem*odulating or redigitizing information for computer reading. Developed to transmit data for air defense in 1962, the modem was quickly adapted to business and government use. The high costs of transmitting data long distances directly over phone lines led to 'packet switching', dividing messages into smaller packets of digital code that could be passed through modems, via nodes (linked computers), to their final destination. By 1969, the US military had developed a decentralized computer network, partly in order to prevent the total destruction of irreplaceable data in the event of a nuclear attack on centralized computer resources. The first network for the military's advanced research projects agency, ARPANET, originally linked only four mainframe computers in California and Utah. The military use of this network gradually expanded, and it was used to send email and post messages on electronic bulletin boards. The development of ethernet technology in 1973, for transmitting packets of data over cable, made networking economically feasible beyond the military and government. By the mid-1970s, the system for passing packets of information was improved with the development of critical software for transmitting data *between* emerging networks (thus making possible an 'internet'). The transmission control protocol (TCP) converts messages into streams of packets, and then reassembles them into messages at the destination. The internet protocol (IP) addresses the problem of routing packets across multiple nodes, and even across different network standards. With public-domain TCP/IP software, numerous networks eventually were able to communicate. The military lost control over the Internet in 1983, when civilian government agencies developed their own networks, and nodes were divided into domains. These include the familiar 'gov,' 'mil,' 'edu,' 'com,' 'org,' and 'net.'

In the 1990s, commercial and university Internet service providers made it possible for PCs with modems to access the Internet. As late as 1992, Internet sites were roughly divided between government, educational, nonprofit, and commercial purposes. Only after 1995 did the tide shift to the 'dot coms.' While electronic packets were transferred via server computers to client PCs, computer users required navigation tools to locate desired electronic files. The earliest of these location tools were called 'gophers' (developed in 1990 at the University of Minnesota, and named after the university's mascot), which provided lists of files (organized by topic) either to local networks or, via Telnet, to remote users.

The gopher system evolved into the World Wide Web, which allowed client computers to link to documents via 'interface browsers.' The first browser appeared in 1990, when Tim Berners-Lee at CERN, an international scientific organization based in Geneva, Switzerland, created the hyper text transfer protocol (HTTP), which standardized communication between large servers and their client computers (often PCs). A text-based Web browser that appeared in January 1992 allowed PCs access to both text and media, but it still required users to type lengthy addresses. By 1993, Marc Andreessen (when he was 23) of the University of Illinois developed a graphic Web browser called Mosaic, which in 1994 evolved into Netscape (followed the next year with Microsoft's Explorer). This browser allowed for the now-common practice of pointing and clicking the mouse to gain access to a Web page or electronic site. The development of the graphic browser, and the marketing of Internet services (especially America On-Line), led to a dramatic change. With improvements in programming language on the Web (including Java), sound, animations, and much more became available to Web users. The proliferation of websites led to the need for search engines, beginning with Lycos in 1994, soon superseded by Yahoo (1995) and then Google (1996).

The final (so far) piece in the modern puzzle of the PC is the introduction of wireless linkage of internet to computer devices through a router. Wi-Fi was made possible in 1985 when the United State government opened a number of wireless frequencies for license-free use. A number of efforts were made to standardize router transmission and increased speed at affordable costs. By 1999, Wi-Fi was practical for home and office use.

Web use grew rapidly: In 1990, 313,000 computers were linked to the Web; 10 million had joined by 1996; by 2001, 109 million computers were online globally, and nearly 3.9 billion people worldwide had access by 2018. Surfing the 'net' and sending email messages has become a daily leisure-time obsession across the world.

Digital Extensions: Computer Games and Smart Phones

We should not neglect the range of new technologies that were based on or accompanied the digital revolution. Especially important were computer games. William Higinbotham's 1958 invention of a game called "Tennis for Two" (later Pong) was the humble start. No more than a digital dot bouncing off dashes, this first video game was first merely a diversion for computer scientists. It was followed in 1961, with "Spacewar!" in which primitive spaceships annihilated one another with blips of digital light across a black and white TV screen, another toy for computer nerds. It took another decade, however, for the video game to be packaged for arcade and home use. Nolan Bushnell's electronic Atari arcade games (1972) supplanted the mechanical/electrical pinball games dating from the 1930s. In a process that followed the shift from public to domestic use of the phonograph, in 1975 Atari offered a home unit for Pong; and in 1977 the Atari 2600 allowed a variety of game cartridges to be played through TV sets. More exciting and fast-paced games appeared with "Space Invaders" (1978) and with an increasing number of Japanese innovations, including the wildly successful "Pac-Man" (1980) and "Donkey Kong" (1981). Sharp competition and the flooding of the market with look-alike games (due to the fact that game cartridges from many companies could be played on Atari's and other consoles) led to a temporary collapse of the video game craze in 1983. But the Nintendo Entertainment System resurrected the thrill two years later, taking advantages of rapidly improved digital processors, with a more powerful game player and strict controls on the access of other company's cartridges to the system. Nintendo's digital hero, Mario, evaded barrels and other trash thrown at him by a gorilla, attracting millions of boys across the globe; Mario, though, was soon challenged by Sega's Sonic the Hedgehog, who whizzed through tubes and over digital obstacles, attracting in time an older, more thrill-seeking player (Figure 20.4).

As the visual palette grew richer with larger game files in the 1990s, the pace of the action increased, especially in the form of graphic violence. Early examples are "Street Fighter" and "Mortal Kombat," first appearing in arcades and bars and then the home. The intensity of kill-or-be-killed games escalated rapidly with "Doom," a computer-based fantasy. Driving this was the shift of sales beyond children to young adults, whose insatiable demand for ever faster-paced games led to hits like "Grand Theft Auto" (1997) and "Halo" (2001).

The video game did more than ratchet up the intensity of the sensual experience. Manufacturers have tried to immerse players in the flow of the game, creating a deep, sometimes even addictive, engagement of players. The movement

Figure 20.4 Late 1970s video arcade game, Pong, a simple electronic form of ping pong, that amused youth before more exciting and sometimes violent arcade games appeared. These arcades were the descendants of coin-op phonograph and kinetoscope arcades.

Credit: *Courtesy of The Strong, Rochester, New York.*

of joy sticks, buttons, and mouses that animated the once thrilling games of "Pong" or "Pac-Man" and so many that followed was transformed by the Wii game system of Nintendo (2006) where the controller tracks the player's body movements, creating an illusion of being in the game. Year after year game designers add new layers of image, sound, and tactile sensitivity, encouraging players to play 'for life,' and not just during childhood. Video game makers also try to alternate doses of challenge and payoff to draw players into the game. Game designers hired psychologists to identify the frustrating and boring parts to eliminate and thus smooth out the game's flow. So powerful have these games become psychologically and even physiologically that many players who grew up on Atari or Nintendo have not abandoned these 'toys' when they grew up. A surprising number continue to play ever more intense video games deep into adult life, sacrificing time for relationships with family and friends, or time spent on some lasting and less 'virtual' form of self-improvement.

Cell and smart phones were a further development of the digital revolution, both radically transforming communication by making interpersonal linkages mobile in the case of cell phones and by reducing the computer to a hand-held information and entertainment device in the smart phone.

The idea of a mobile telephone dates from the beginning of radio; the military and police were early to adopt radio phones. In 1921, the Detroit Police Department introduced a one-way radio dispatching system to signal police in patrol cars to call headquarters on land lines; by 1931, radio communications were two way. In World War II, GE and Motorola developed walkie-talkie mobile phones for the military. Civilian mobile telephony, however, was slow to develop because of cost, power requirements, and the fragility of tube-based phones. ATT introduced an experimental Mobile Telephone Service in 1946 in St. Louis for calls from fixed phones to mobile ones in cars. By 1964 1.5 million phones were on an improved ATT system, which still required an operator to connect mobile phones that had to be linked to car batteries and antenna. Citizen band radios (small and cheap because of integrated circuits) became popular in the late 1970s, giving drivers a way of communicating with each other and were often used to avoid police speed traps.

But the big change came with the development of cell towers that received and passed on signals from mobile phones ultimately to a receiver. As early as 1973, Martin Cooper of Motorola produced a two and a half pound 'Brick' mobile phone. However, Japanese and Western European companies were quicker to introduce cellular technology (still based on analog radio signals) that freed the mobile phone from cars and created full telephonic mobility. In 1983, cell phones in the US allowed only 30 minutes of talking before requiring 12 hours to recharge the battery. They weighed 30 ounces and cost $4,000. Only in 1989 could cell phones fit in a pocket. By 1992, as much else, cell phone service switched to digital (2-G or second generation technology). This led to text messaging. Adoption was slow until service became much faster with mobile broadband technology. By 2002, phone access to the Internet was possible (3-G technology). By 2009, a fourth stage of cell technology allowed for video streaming (Figure 20.5).

Meanwhile, from the later 1990s a wide range of single purpose personal devices came to the market (MP-3 players, digital cameras, personal digital assistants or PDAs, and GPS navigators). Most notable was the iPod of Apple

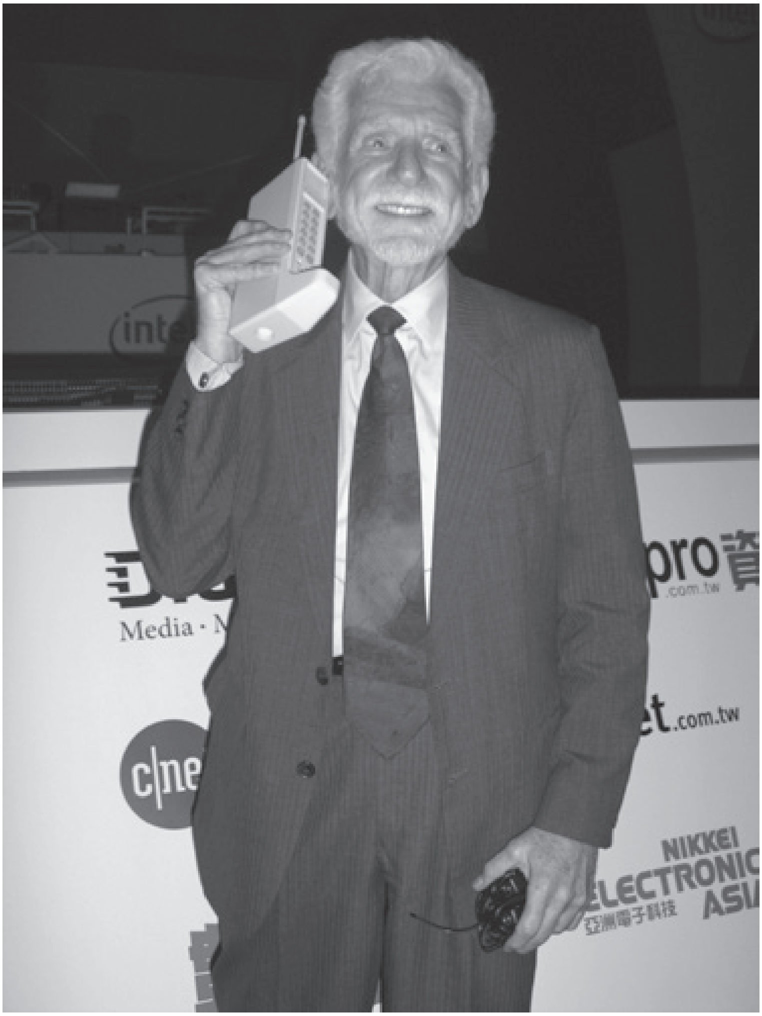

Figure 20.5 A 2007 photo of Martin Cooper, holding the Motorola cell phone he developed in 1973. Note the size.

Credit: *Wikimedia, Creative Commons, GNU Free Documentation License, photo by Rico Shen.*

that quickly dominated the market for downloaded music. Gradually, all these were combined with a mobile phone into the smartphone. Early examples were Symbian in 2001 and BlackBerry in 2002. However, the breakthrough came in 2007 with the introduction of Apple's iPhone that combined the iPod portable media player/miniature computer with the cell phone (and, unlike BlackBerry operated by a touchscreen without cumbersome keys). As in the 1980s introduction of the personal computer and Windows, Apple found itself soon competing with an alternative system, in this case, Android (owned by Google) in 2008. Like Microsoft in the 1980s, Google made the Android system available to any smartphone maker (profiting from advertisements). The smartphone contained in a pocket most of the wonders of the PC, the MP-3 player, the digital camera, the mobile telephone, and more, revolutionizing personal communications, entertainment, and information access in ways that will take years to fully understand.

Computers and a New Debate about Technology

Digital technology has dramatically changed American life in both positive and negative ways. The rapid and continuous upgrading of computer products has revolutionized what consumers expect of technology. Unlike cars from the 1920s, fashion did not drive the buying of new computers or accessories. Rather, the incessant upgrading of one or all components of the PC, tablet, and smartphone created a constant demand for replacements. Nevertheless, consumers have accepted this burden because, with each successive purchase, they receive more bang for their buck, creating the expectation of continuous technological improvement. By the 2010s technological innovation in computers was slowing down.

The computer has transformed the experience of time. It has created the '24/7' culture, in which markets and entertainment are available at any hour of the day. If the nineteenth-century train annihilated time (and space) with the power of steam, the computer certainly completed the process by moving information and communication at the speed of electrons; the internet made for random access across the globe and across time in uploaded images, text, audio, and video. The smartphone has made all this fully portable, accessible with internet service anywhere. The pace of life has dramatically increased with the computer. Mass access to digital technology has become commonplace in a very short time: Whereas it took 38 years for 50 million Americans to own a radio, and 13 years for that many to purchase a TV, only four years after the World Wide Web was available, 50 million Americans were using it. The computer and the Internet have also dramatically sped up many processes, from sending and receiving mail and retrieving and recording information, to buying and selling stock. Hypertext links help Internet users move quickly and sometimes deeply into a subject or interest. Who needs to visit a library or search a book for information? Who needs to go to the theater, record store, or wait for a TV show to hear and see the latest hit audio or video? For that matter, no one has to stick to current entertainment offerings; much of the past is immediately available online via streaming services.

At the same time, the speed and ease of access to extensive information may reduce people's attention spans, and their willingness to read long books or ponder complex writing or images. Fewer may be willing to dig deeply into a topic—or even to use information sources that are not digitized, and that require turning off the computer or smartphone and walking over to the library. To 'surf the net' means to slide quickly from one web site to another. The computer's capacity for multitasking encourages users to expect to do more than one thing at a time. The computer's speed creates pressures to accelerate the pace of life. Email and text messaging, for example, has led to the expectation that messages are answered in hours or even minutes, and correspondence has become sloppy. Texting has become a substitute for verbal exchange. As Thomas Eriksen pessimistically remarks, "growing numbers of people become accustomed to living in a world where colourful fragments of information flit by, lacking direction and cohesion [and] do not see this as a problem." Computers undermine the "pleasures of slow time" (like fishing or savoring a skill) and create instead the "tyranny of the moment."[1]

The PC has had an even greater impact on the way that people relate to each other. As William Gibson anticipated in his 1984 novel *Neuromancer*, computers have created a virtual society, providing expanded experience and knowledge without costly travel. There is much evidence that people use computers (especially email) to maintain and facilitate family and special interest groups, which is especially necessary in a society as mobile and as dispersed as America has become in the twenty-first century. Internet bulletin boards and listservs give millions access to the ideas and information of dispersed experts and enthusiasts in thousands of topics. For Bill Gates and many others, the computer created a world available at a click of the mouse, letting its users make friends, explore the world, and conduct business at home. Email and social media even foster 'skin' contact by making possible the arrangement of family reunions or senior citizen get-togethers. The Internet provides a world formerly unavailable to the infirm, the lonely, or even just those seeming too busy to meet friends for a long lunch.

Certainly, the smartphone with continuous internet access has dramatically changed the lives of youth. For example, these technologies have played a big role in the decline, need, and desire for access to the drivers' license at 16. In a sense, cruising the internet has replaced cruising the streets that had been a common way for the young to socialize and win freedom from their families from the 1930s to the 1990s. The search for the chance encounter with hands on the wheel of the car can be done more efficiently, safely, and cheaply with fingers on the touch screen or on Facebook, Twitter, and Instagram.

However, just as the computer and Internet have provided access to ever-wider cultural vistas, they also have isolated the individual at the keyboard or touch screen, and therefore can reduce face-to-face social interaction. Both radio and TV made it possible for people to participate in mass culture from the privacy of their own homes. The PC and smartphone have simply accelerated this trend, as the user has become the isolated participant in an ephemeral global culture of Web pages, chat rooms, and email. Critics insist that the virtual society is no replacement for real society. As many educators have noted, the hours that children spend playing computer games are taken away from social interaction with their peers in physical play and conversation. Some argue that the computer (or video) game has contributed to growing obesity.

Social skills—learning to communicate and compromise—take time; and computer time, especially when it becomes a substitute for relating to real people, may lead to a deterioration of those skills. Partially because of the rise of the smartphone, by 2015 American teenagers were spending about nine hours a day looking at electronic screens.

Computers have certainly affected the world of work and economics. As early as 1948, MIT's Norbert Wiener predicted in his book *Cybernetics* that the age of mechanical power had reached its zenith, and that information and communications would be the source of future wealth and influence. Computers shifted costs of production from raw materials and manufacturing to the research expenses required for making the first unit. (Examples include software and even the microprocessor, the material of which is a very small percentage of their value.) And, if computers have not automated most jobs and caused massive unemployment, as many feared in the early 1950s, they certainly have impacted work and the jobs that people have. Not only have whole occupational categories nearly vanished, but the Internet and other technologies (such as cheap satellite telephone service) have created a global workforce, often erasing the disadvantage of long-distance employees. Note the recent growth, for example, of service and sales workers in low-wage countries, serving the American market.

The computer clearly has increased individual choice and freedom. The ease of transfers of money and other transactions by computer has dramatically extended markets, (as with Amazon that appeared in 1994 and the way that Internet shopping has undermined 'bricks and mortar' stores). And some products that formerly took bulk form (such as recorded music, books, magazines, newspapers, and video) can be digitized for instantaneous electronic shipment. The ease of getting to global markets via the Internet has tended to level the playing field (at least for the present), allowing small and entrepreneurial companies to compete with the big corporations. To be sure, the Internet faces a huge hurdle in delivering goods to people. It cannot overcome the desire of consumers to touch, smell, or test goods. Still, the Internet makes individual choice almost limitless and openness inevitable, despite efforts of closed societies to keep pornography and politics on the Web from their citizens.

At the same time, this vast expansion of choice may also lead to personal confusion. Since the late 1990s, the PC and smartphone have become multipurpose machines, used as a fax, post office/telephone, copier, radio, and even TV. In its portable form as tablets and smartphones, it has freed users from the fixed desktop computer. The Internet has become a site for education and business, but also shopping, entertainment, and even gambling, breaking down the traditional barriers between work and play, sometimes intruding into productivity to the irritation of employers.

Yet, all this information may simply clutter people's lives, creating what David Shenk calls "data smog." Moreover, the sheer number of Web sites means that less information is shared, encouraging "a cultural splintering that can render physical communities much less relevant and [discourage] free people from having to climb outside their own biases, assumptions, inherited ways of thought." Shenk argues that computer users need more "filters" to allow them to focus.[2]

Even those who find critics like Shenk to be alarmists agree that the computer revolution has created new questions about privacy and crime. Skilled hackers can get access to private or valuable records, while the malicious can destroy data in millions of PCs by sending viruses via email or downloaded files. Cyberstalkers on computer bulletin boards or in chat rooms have become a major anxiety, especially when they prey on innocent children. And false information can spread rapidly, sometimes from foreign sources. The Internet has been used to recruit and motivate terrorists as well as to link like-minded people across vast distances into positive cultural, political, and charitable activities. Advertisers have found it amazingly easy and cheap to clog email with unwanted commercial messages (spam), despite near universal outrage. Access to Web pages across the globe inevitably raises questions about the rights of local authorities to limit access to smut, gambling, or other information that might not be allowed on the street.

There are some who contend that the impact of the digital revolution has been exaggerated. Robert Gordon in his monumental *Rise and Fall of American Growth* (2016) observes that computer technology has not had the long-term positive impact on economic growth as expected. He argues that the escalating capacity of computers has slacked off considerably since 2006 and that even the massive investment in digital technology has not had a noticeable impact on achievement in schools.

As true of so many technologies, the computer revolution can have both positive and negative impacts. Its ease of access can vastly extend experience, as well as create obsessive behavior and sensory overload. The Internet can create global contacts and understandings, while diminishing the influence of local cultures dependent on physical interactions. It can intensify inequalities between those with access to the Web and those without it. Cyberspace is contested space between those who see the Internet as a market and as entertainment, and those who hope that it will become a venue of learning and social movements that transcend boundaries and time zones. Like much technology, the computer revolution has had many, often unanticipated, effects.

Notes

1 Thomas Eriksen, *Tyranny of the Moment: Fast and Slow Time in the Information Age* (London, Pluto Press, 2001), 20.
2 David Shenk, *Data Smog: Surviving the Information Age* (San Francisco: HarperOne,1997), 125.

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21 Modern Americans in a Technological World

As we write this third edition, many voices in the world worry that most of the significant innovations in science and technology have already occurred and that both product and process innovation will, therefore, be sluggish in the future. Yet others fear instead that new technologies such as artificial intelligence, self-driving cars, and additive manufacturing (3-D printing) will alter life as we know it in many ways. One lesson of this book is that the course of technological innovation is unpredictable. Another lesson, though, is that technological innovation has far-reaching effects on society. Some of these effects are widely perceived to be good while others are viewed with dismay. It is thus prudent to prepare ourselves for possible technological futures.

We will briefly review the recent history of technological prediction. We will appreciate that technology has been viewed with both excitement and fear for decades. We will focus in particular on how technology has been thought to affect employment, economic prosperity, the environment, and personal life.

Technological Forecasts Past and Present

General Motor's "Futurama" exhibit at the New York World's Fair of 1939 encouraged Americans to look forward to 1960 when they would drive radio-controlled cars on superhighways that provided "safety with increased speed." Forecasters in 1941 correctly predicted the growth potential of pharmaceuticals, nuclear power, and television. They also, however, foresaw great advances (which have not transpired) in long-term weather forecasting, photosynthesis, and prefabricated housing. Their success rate is typical of those who have dared to predict the future. Even when one thinks one sees the early stages of the emergence of new technology, it is difficult to foresee how successful it may be. Decades after the first "horseless carriage" hit the roads, urban planners still could not imagine the dominant role that the automobile was destined to play in American society. In recent decades, producers have been disappointed by the failure of picturephones, and pleasantly surprised by the success of cell phones and fax machines.

Guessing at new areas of technological discovery is even more dangerous. Writers of science fiction, at least, had imagined space travel centuries before it became possible, although they could not be very precise about the particular form this travel would take. On the other hand, nobody imagined radio before scientists discovered the existence of electromagnetic waves.

We should thus be particularly wary of predicting the future rate of technological innovation as a whole. The general manager of the National Machine Tool Business Association worried in the mid-1920s that the age of invention was drawing to a close. With the advantage of hindsight, we now know that although few new products reached the market in the interwar period, research was well under way that would unleash a host of new products on the postwar market.

At present, there are good reasons to be both pessimistic and optimistic about future rates of innovation. Some economists point to sluggish growth in productivity in the last decades in most developed economies to suggest that at least process innovation has slowed. Many economists and historians then suggest that we may have reached a point of diminishing returns in both science and technology: We have already made most of the important discoveries, and further developments will tend to be of less importance. Calculations of the impact on economic growth of industrial research labs suggest that the average researcher has about one-seventh the impact of a researcher in 1950. Yet optimists point to the simple fact that technological innovation has always been unpredictable. The rate of innovation rose through most of the last two centuries, but unevenly. It is entirely possible to imagine future technologies that will have a massive impact on our lives. Self-driving cars and trucks may yield tremendous savings in transport and commuting costs. Artificial intelligence may allow computers to replace humans in a host of tasks that rely on analyzing data. We may also see important effects of recent technologies: Just as it took decades for the full implications of both the First and Second Industrial Revolutions to unfold, the most significant effects of increased processing power may lie ahead as computer chips find their way into a host of devices in factory, home, and office. While pessimists may worry that the growing service sector provides less scope for innovation than the declining manufacturing sector, optimists suggest that computers and especially artificial intelligence may be about to revolutionize the service sector. Pessimists may fear that the United States is no longer as dominant as it once was in many fields of technological innovation; optimists note that the global rate of innovation should rise as more countries develop innovative potential.

An Abiding Ambivalence: Modern Technocritics and Futurologists

In the 1930s, futurologists like Lewis Mumford predicted that electricity would free cities from air-fouling industry, and instantaneous communications would allow for decentralized communities and choice where people lived and worked. However, as we noted in Chapter 14, many other Americans in the 1930s were deeply suspicious that technology was responsible for the Depression, and blamed machines for displacing workers. Charlie Chaplin's 1936 film, *Modern Times*, portrays a nearly workerless factory in which the boss supervises assembly line workers by television from a comfortable office, and even experiments with a mechanical lunch-feeder to keep workers always on the job.

These divergent views of the technological future persisted after 1945. There was widespread American confidence in the 'technological fix'—a faith in technology solving all problems, with less effort and cost than required to change social behavior or political realities. Nuclear power was far more effective in overcoming problems of air pollution and depleted fossil fuels than was trying to persuade people to conserve. This technological optimism permeated the thinking of 'futurists' like Herman Kahn and Alvin Toffler. In the 1950s, Kahn became notorious when he advocated that Americans "think [optimistically] about the unthinkable" effects of thermonuclear war. From the late 1960s, he argued that energy and other resources were in no danger of exhaustion. He predicted incorrectly that innovation would mean a reduction by half in the hours required at work by 2000. In 1967, in *The Year 2000*, Kahn forecast a future in which scientists (rather than politicians and business people) would make the major decisions, and lifelong education, guaranteed personal income, and extensive leisure would become realities. Even Kahn worried that these changes could undermine the work ethic and create a hedonistic society without motivation or ethical standards, but he had faith that a minority of educated technicians could monitor and support the rest of the population.

Toffler's *The Third Wave* (1980) claimed that the next technological wave would eliminate dependence on fossil fuels and shift to limitless energy sources (alcohol fuel from grain, as well as nuclear and solar power). The old centralized mass media would give way to interactive and individually chosen media. Thanks to microelectronics, consumers would be able to design their own products, to be manufactured by robots regulated by a skilled human workforce. Labor would no longer be arduous and confined to centralized authoritarian factories or offices; instead, the home-based computer terminal would allow work to 'return' to the home, where one could adapt working hours to personal needs. Toffler found in the technological future the solution to problems of pollution, resource depletion, and alienating work and social life.

Challenging these views was a vocal group of technological pessimists. These writers shared with many nineteenth-century romantics the belief that technology had become essentially 'autonomous' or separate from social needs and operated according to mechanistic rules. They feared that technology was dehumanizing. Aldous Huxley's *Brave New World* and George Orwell's *1984* haunted many thoughtful Americans, with their vision of a technological future dominated by passive artificial pleasures and the thought control of 'Big Brother.' Where Toffler celebrated working from home, pessimists worried that such workers felt socially isolated and were less able to combine with other workers to fight for improvements in pay or working conditions. The increased pace of technological change only seemed to propel humanity into a world in which gadgetry replaced social life, and new problems of pollution and affluence replaced the old concerns of toil, insecurity, and scarcity. Many worried about nuclear war—and shared with many scientists a profound doubt that expensive systems of missile defense could provide a 'technological fix' against nuclear attack. More subtly, they feared that technology did not seem to make people happy or to create social harmony. They—correctly—doubted that all of Kahn's and Toffler's optimistic projections would come through. The partial meltdown of the Three Mile Island nuclear plant in 1979 and the crash of the Challenger space shuttle in 1986 enhanced skepticism that 'experts' could achieve technological fixes for complex problems. While some technological 'pessimists' seemed to look back nostalgically on a 'lost' past and fearfully toward the future, others advocated a technology that was 'appropriate' to the dignity of work, a clean environment, and a less materialist culture.

Technology, Jobs, and the Postwar Economy

As noted in Chapter 14, technological innovation was an important cause of economic prosperity after 1945. Undoubtedly, the increases in productivity that were observed both between the wars and in the decades after World War II would not have been possible without advances in production technology.

We suggested in Chapter 14 that an imbalance between product and process innovation contributed to the unemployment experience of the Great Depression. Nevertheless, we also noted in that chapter that process innovation had had no long-run impact on rates of unemployment since the Industrial Revolution. The challenge is to move workers replaced by technology into new jobs producing new goods or services. Immediately after World War II, many industrial workers worried that the unemployment of the Depression years would return, now that the munitions factories were no longer needed and new technology would take away jobs. However, in the postwar decades, American workers experienced low levels of unemployment while enjoying the ability to devote higher incomes to a wide range of both new and old goods and services. Yet when unemployment rose in both the 1970s and 2000s, there were understandable concerns that technology was at least in part responsible.

During the Depression, Congress had considered legislating a 30-hour workweek. During decades of postwar prosperity, American workers devoted increased incomes to consumption rather than seeking decreased work hours. American workers have a much longer work year than workers in most European countries (where much longer vacation times are common). If there is continued process innovation in the future (see below), then there may again be discussion of reducing the hours that the typical American spends in work. This will be especially likely if it is not clear where displaced workers might go.

Despite continued prosperity, the specter of automation began haunting wage earners in the 1960s. Starting in 1945, engineers at MIT, supported by contracts from the Defense Department, developed the precursors to the modern computerized factory in numerical-control machine tools. By the early 1960s, these devices entered civilian manufacturing, to the distress of skilled machinists. At the same time, unionized dockworkers faced containerization, printers confronted new typesetting machinery and computers, and a massive machine called the continuous miner (and strip mining) threatened traditional miners. Fears that numerical-control machine tools and later robots would displace skilled machinists led unions to demand retraining programs for displaced workers, and higher job classifications for those who remained. By the 1980s, integrated computer technology further reduced the role of the machinist; increasingly, the designer set up machinery directly from a terminal. The ability of computers to track and coordinate the flow of materials through the production process centralized control and eliminated jobs. The role of the highly paid, mostly male factory and construction worker declined sharply: this worker constituted a quarter of the labor force in 1950, but only an eighth by the 1980s.

The service sector absorbed many workers displaced from manufacturing in the twentieth century. There are thus understandable concerns that workers displaced in services may have no place to go in the future. Fears that computers would replace masses of service workers have not yet been realized: Indeed, economists have struggled for decades to detect a significant effect on worker productivity of the computer revolution. However, developments in artificial intelligence (AI) may allow computers to replace humans in many jobs that involve decision-making grounded in data analysis. Of course, the future of AI is unpredictable. There have been rapid advances in areas like voice and image recognition in recent years, but other types of human reasoning have proven harder to duplicate. Importantly, computers are increasingly able to recognize patterns in the vast masses of data that modern information technologies generate. Some analysts thus predict that as many as a third of service sector jobs might be replaced over the next decade or two. However, AI may also generate new products: In drug research, for example, by analyzing patterns in the effects of current drugs it may be able to suggest new chemical combinations. AI may also revolutionize hiring processes, allowing firms to match applicants to jobs better, thus reducing job turnover (though firms must take care that AI algorithms treat all applicants fairly).

There may also be continued process innovation in manufacturing. Increased use of industrial robots already means that some automobile factories operate with half the workers of just a decade previously. Yet these robots still perform only very simple tasks and usually operate separately from workers—who still tend to dominate intricate tasks of final assembly. The robots of science fiction that interact with humans may emerge with developments in artificial intelligence: Robots who could perform complex actions in response to vocal commands might transform industry. AI already guides robots around warehouses (Figure 21.1).

We should also mention 3-D printing, the act of creating objects by slowly adding material as directed by a computer program. Plastics are especially well-suited to 3-D printing, but metals can be printed, and new materials are under development that may prove even more suitable. 3-D printing already allows low-cost production of one-off items: These no longer require extensive machining by a skilled worker. Medical implants and prototypes of new products have been important outputs. The range of goods produced in this way is expanding: Shoes are manufactured to fit particular feet. Very complex components for aircraft engines and spacecraft are also printed. Importantly, printing can yield dramatic savings in the use of expensive materials. At this point, 3-D printers have probably created more jobs than they have displaced, for they allow us to do things that were infeasible before. However, as the technology improves printers will increasingly replace workers in industries that produce small numbers of goods.

It is even harder to predict the effect of self-driving and electric cars. Both types of technology have advanced very quickly in recent years. Electric vehicles may eventually prove to be much easier to produce because they involve

Figure 21.1 Industrial robots in a medical research laboratory.

Credit: *Courtesy of National Institutes of Health, National Human Genome Research Institute Chemical Genomics Center, Wikimedia Commons.*

fewer components—but this will depend on further advances in battery technology. Self-driving cars might lead to a dramatic reduction in car production if most people abandon car ownership to hail a car as they need it. Self-driving cars and trucks (and the drones we discussed in Chapter 18) could lead to massive reductions in employment in transport and delivery services (and AI promises to plan delivery routes far better than humans can). Moreover, if self-driving cars reduce congestion and the need for parking lots they will change the shape of cities and reduce the need to build certain types of infrastructure.

For decades many Americans have feared that the rapid transference of technology abroad has taken away the advantages that blue-collar American workers enjoyed in the 1950s and 1960s. Japanese and other Pacific-rim Asians became innovators in robotics, for example. Low-cost electronic communications allowed insurance and computer companies to employ service employees from low-wage nations. Reduced transport costs and global markets permitted manufacturers to hire low-wage workers in other countries. The technologies outlined above may cause industrial jobs to migrate back to the United States. As machines replace workers, there is less advantage in employing low-wage workers abroad. There are advantages to having computer-automated machinery located close to those who program it so that they can quickly spot and react to problems. One advantage of 3-D printing is that one can potentially respond promptly to changes in consumer demand: It thus makes sense to locate printing facilities close to markets. The question remains: Will the return of jobs to the US in the form of robots help many Americans in search of manufacturing jobs.

Environmentalism and Growth

Accelerated technological change after 1945 also forced Americans to reevaluate the impact of modern industrialism on the natural environment. From about 1900, Americans took an interest in the conservation of wilderness, and in creating sustainable agriculture and forestry. The new environmentalism had a broader focus: It looked to the impact of farming, mining, and manufacturing on the 'biosphere.' In her *Silent Spring* (1962), Rachel Carson showed the impact of chemical pesticides (DDT especially) and fertilizers on water quality and the food chain. She inspired many scientists to study the wide-ranging and unanticipated environmental costs of refineries, automobiles, mines, and factories. Nevertheless, the older reverence for the 'rights' of the natural world remained at the heart of the environmental movement. Barry Commoner in his *The Closing Circle* (1970) proclaimed "Four Laws of Ecology" that neatly summarized this perspective:

Everything is connected to everything else.
Everything must go somewhere.
Nature knows best.
There is no such thing as a free lunch.[1]

The environmentalists' concerns mounted with increasing evidence of the ecological costs of technology and growth. In 1943, the glamorous boomtown of Los Angeles experienced its first bout with 'smog,' resulting from fog mixed with industrial and automobile emissions. Power outages in New York in November 1965 that affected thirty million people brought home how dependent Americans had become on a complex and imperfect energy/power system. In 1972, 95 percent of US energy was supplied by burning fossil fuels. Americans, representing 6 percent of the world's population, used 35 percent of its energy in 1973. In that year, the OPEC price increase and its temporary ban on sales of oil to the United States starkly revealed US dependence on foreign oil. Groundwater contamination from storage tanks, hazardous waste sites, and landfills was becoming a significant problem by the 1960s. Love Canal, an industrial dump that had become a housing development in the 1950s in Niagara Falls, New York, had begun sinking in the mid-1970s. In 1980, after residents complained of mysterious diseases, Love Canal was declared a disaster area and 719 families were evacuated. When oil spills fouled California beaches in 1967, and 250 million gallons of crude oil polluted the beautiful coastline along the Santa Barbara Channel in 1969, the cry rose against offshore petroleum development. In 1969, the Cuyahoga River that flowed through Cleveland burst into flames because of an unidentified oil spill. By the early 1970s, ecologists attacked the practice of strip mining for defacing the landscape.

The environmental movement was far more successful than was the response to automation: Between 1965 (when the Water Quality Act passed) and the early 1970s, several environmental bills became law. Earth Day on 22 April 1970, gave national media attention to the problem. The Air Quality Act (1967) required states to submit plans to Washington to control air pollution (Figure 21.2). The National Environmental Policy Act of 1970 demanded environmental impact studies from developers of potentially dangerous industrial sites; the Environmental Protection Agency was established at the same time. In 1972, the pesticide DDT was finally banned. Local efforts to clean up decades of industrial and sewage pollution in Lake Erie, Lake Washington (Seattle), and the Cuyahoga River were relatively successful. Local action reduced air pollution in Los Angeles, Pittsburgh, and New York. In 1966, Californians were required to have a catalytic converter on all new cars. In response to the threat of dependence on foreign oil and domestic petroleum depletion, there was a flurry of interest in solar, geothermal, and wind power (and other new technologies) from the late 1970s. Almost 10 percent of the energy in the United States in 2015 came from renewable sources such as solar and wind. This progress has been aided by continued technological innovation that has dramatically lowered the cost of wind and solar power—developments in batteries may be particularly important going forward to deal with the fact that both wind and solar power are necessarily produced unevenly through time.

Environmental protection has been controversial. While Americans wanted clean air and water, they also worried about the impact that environmental regulations might have on both employment and the cost of living.

Figure 21.2 Smog covers George Washington Bridge, New York, 1973.

Credit: *National Archives and Records Administration.*

Whereas environmental regulation enjoyed bipartisan support in the 1970s, there have been fierce political battles since regarding particular regulations. This has especially been the case as scientists have suggested since the 1980s that human actions are causing a dangerous increase in global temperatures. Some political leaders advocate strong policies to combat 'greenhouse gas' emissions while others either deny the existence of global warming or suggest that a 'technological fix' will address the problem without any need for government policies. We can see in this polarized debate the broader disagreement between those who believed that technology could 'fix' the problems that it had created (and that environmentalism is a threat to business) and those who thought that a changed social ethic was also required. And, as we noted in Chapter 15, changing values is very difficult as Americans have continued to demand big gas-consuming vehicles.

Technology and Personal Life

Intellectual battles over the impact of technology on jobs and the environment often encouraged a still broader concern about the effect of innovation on personal life. From the beginnings of industrialization, visionaries predicted that mechanization would lead to a progressive and universal reduction of work—as well as mass affluence. As we saw in Chapter 12, optimists assumed that the mechanization of the home would free women for broader participation in public and economic life. The famous economist J. M. Keynes wrote in 1931 that in the near future "man will be faced with his real, his permanent problem—how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him, to live wisely and agreeably, and well."[2] Further mechanization could only free all for longer and richer hours of leisure. Yet increased free time also disturbed many: Early in the twentieth century, cultural conservatives anguished over what wage earners would do with their free time. The massive increases in productivity postwar have resulted, though, in increased consumption rather than increased leisure.

Early twentieth-century intellectuals like Simon Patten and Bertrand Russell argued that technology would create a mass-consumer culture wherein old class divisions would disappear. Mass-produced clothing would reduce social distinctions, especially after work. The radio, the phonograph, and the movies could bridge gaps between peoples of different ethnic groups and regions. These expectations seemed to become a reality to the generation of affluence following World War II. Popular magazines gloried in the apparent fact that old luxuries were becoming mass-consumer goods, and all Americans were joining the middle class—to the envy of the rest of the world. In the 1950s and early 1960s, academic sociologists predicted the convergence of social classes as an inevitable consequence of postindustrial consumer society. Work, even if boring and repetitive, was an unavoidable and ultimately satisfactory price to pay for the freedoms and comforts of consumption and leisure.

Intellectuals regularly challenged the tendency to equate manufactured goods and mass entertainment with 'the good life.' This critique had roots deep in the romantic movements of the early nineteenth century and survived in the early twentieth century in the rising chorus of disenchantment with technology's impact on culture. While technocrats praised a productivity that brought high wages and consumer choice, humanistic intellectuals, like Erich Fromm, argued that mass-assembly jobs disabled workers. Such labor prevented wage earners from marshaling the initiative and imagination required for anything more than passive leisure and manipulated consumption. Mass-production work, these critics argued, diminished the capacity for spontaneity and community.

Postwar affluence also brought forth similar criticism. The American sociologists Vance Packard and William Whyte found that mass consumption produced not happy families but status-seeking consumers. The economist Staffan Linder, in *The Harried Leisure Class* (1970), argued that affluence had not brought additional leisure. Instead, with rising real wages, the 'cost' of free time rose, obliging 'rational' wage earners to work additional overtime and to moonlight; economic maximization induced them also to intensify their 'consumption' of leisure time by purchasing time-saving devices (like stereos with remote controls as opposed to books). Ironically, this meant that leisure hours were rushed with the 'work' of consumption. People might long for community and self-expression, but goods got in the way of their enjoyment of time and each other. Another economist, Fred Hirsch (*Social Limits of Growth*, 1974), noted that social harmony had not been generated. Instead, members of the great 'middle class' crowded each other on the beach; they found that the more they had, the more they competed with others who had still more. Finally, economist Tibor Scitovsky in *The Joyless Economy* (1975) argued that Americans' technological and economic success made them less able to enjoy the fruits of technology in leisure and sophisticated consumption. The skills of sophisticated leisure and consumption were less valued than those of invention and business. Thus, much of the time saved in work, Americans spent watching television, driving cars, or shopping, instead of cultivating the arts, reading, conversation, or even tasty cuisine. Technology became not a means to an end but an end in itself. These concerns persist in the twenty-first century.

Particular technologies have evoked specific concerns. We might pay special attention to communications technology. As we noted in Chapter 20, cell phones, email, and social media make it much easier to keep in touch with lots of people. There are concerns, though, that they thus distract from close personal ties. We spend family dinners texting our friends, and evenings on computers rather than in conversation. We feel pressured to keep on top of our emails and text messages. The costs of these new communications technologies may be less evident than the benefits but should not be ignored.

Government Policy and Technological Innovation: Lessons from the Past

We should not leave the impression that technology is some autonomous determinant of change in human societies. Technology both influences and is influenced by developments in the political, economic, social, cultural, and other spheres. Influences on technology are likely most significant in the early stages of a technology when fundamental questions about technological possibilities are explored: At that point society, albeit imperfectly, in various ways identifies its needs and wants and how these can best be satisfied. Once a technology (and especially a technological system) is in place, it develops a momentum of its own that limits the range of further technical exploration.

How might governments encourage innovations with beneficial effects but discourage innovations with adverse effects? Most of the innovations that we have discussed in this volume have emerged in the private sector, either from the hands of independent innovators or industrial research laboratories. The clearest role for government in such cases was the maintenance of a patent system that would reward innovators while not unduly preventing others from adapting and building on their innovations. There may still be areas for improvement—some have claimed that industrial research labs abuse the patent system with a series of minor enhancements designed primarily to keep competitors out of their industry—but there is little justification at first glance for government expenditure.

Some of our innovations have had government support. The government has always taken an interest in military technology. There is a long-standing debate on the extent of the civilian spillovers from military research. We would certainly expect that civilians would have gained much more if the money spent on the military had been devoted to nonmilitary research. However, for various reasons, this was not politically feasible. We cannot deny, however, that there have been substantial spillovers. In the early days, there was little difference between military guns and civilian guns, or between military ships and civilian ships (and government armories played a significant role in the development of the American System of Manufacturing). In the past century, many would argue that military and civilian technologies have increasingly diverged. Military aircraft stress high speed and maneuverability, and relatively little attention is paid to cost. Commercial airlines trying to reduce cost per ton-mile of passenger travel may find little of use to them.

One should not take this argument too far. Many would say that the commercial airplane is the single most crucial spinoff from military research. Not only was aircraft production given a boost by World War I, but the Navy continued to finance research during the interwar period. Airplanes were complex and thus well suited to the efforts of industrial research labs: With commercialization well in the future, these labs relied heavily on government funding through the interwar years. Then, in World War II, the development of the jet engine was among the areas that saw rapid advance due to military research spending.

Not all government research support has been oriented toward the military. The space program is one example (although military motives were not absent). This program has given us Teflon, communications satellites, and the promise of widespread future benefits from experiments in space and from space exploration itself. The Atomic Energy Commission has done much to harness the atom to peaceful power production (although many might wish it had never done so). Many government departments financed the early development of the computer. Medical and agricultural research are two other areas in which government has long played an active role.

Moreover, the American government has a long tradition of backing scientific research. Many technological innovations (such as X rays, lasers, and biotechnology) were based on publicly supported scientific discoveries. As technological innovation increasingly occurs near the frontiers of scientific knowledge, the importance of a productive scientific establishment has steadily increased. American scientists have used this fact to lobby for increased government support since at least the 1920s. Ironically, this government support was long grounded in a misguided belief that technology is simply applied science: An appreciation that technology is and should be a valuable input into science itself has encouraged greater emphasis on corporate-university partnerships in recent years. The challenge here is to find the right balance between the secrecy and profit motive of technological research and the open disclosure on which scientific advance depends. The debate over government involvement is global as American traditions of free markets clash with the state capitalist models of the European Union and especially China.

As we saw above, it is challenging to predict the future course of technological change. Governments have often guessed wrong when they have attempted to pick winners by supporting particular technologies. Still, government policies could legitimately be biased toward certain goals. Improving the environment is the most obvious of these. Government regulations have encouraged the automobile industry, for example, to devote considerable innovative effort to reducing emissions. As technology has become more complex, concerns regarding safety and health risks have also grown: Government policies such as drug screening have an important role here as well. Governments might also want to act to ensure a rough balance between product and process innovation, though this may be difficult in practice due to the unpredictability of technological innovation.

Technology and Social Change

This book has been about the complex linkages between technological and social change. A persistent American doctrine has been the expectation that invention could solve all social problems. Another pervasive notion is that the United States was blessed with particular advantages because of its Yankee ingenuity. Recent trends suggest that these orthodoxies are, at least, incomplete: American superiority has vanished with the coming of a global technological network of satellite communications and the portability of the computer chip. The desire of other peoples to share in the bounty of innovation has challenged our educational system and our culture to find new ways of competing. And others are forging ahead in infrastructure technology, while the US is lagging behind. Technology has perhaps created almost as many problems as it has solved—even if we may dispute which set of problems is worse. Whatever you may think of the critiques of modern industrialism, they do suggest that technology has not, and probably cannot, make our choices for us. What sort of society we wish to become depends on how we evaluate those choices between growth and environment, between goods and free time, and between change and continuity. Technology helps inform and direct those choices. Nevertheless, they remain ours to make.

Notes

1 Barry Commoner, *The Closing Circle* (New York: Random House, 1971), 33, 39, 41, and 45.
2 John M. Keynes, *Essays in Persuasion* (London, 1931, Norton, 1963), 370.

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