THE LEVER OF RICHES

Technological Creativity and Economic Progress

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To the Memory of My Mother
Who did it all by Herself

technological progress were limited, and its net effects, taking into account both benefits and costs, were surely negative. Political competition did not inevitably lead to war any more than competition between firms inevitably leads to illegal actions between them. Perhaps the best of all possible worlds was one of peaceful threats without major conflagrations, as characterized Europe between Waterloo and Serajevo. Insofar as war accompanied political fragmentation, it was a price paid, not a benefit enjoyed. In any case, political unification did not necessarily mean peace, as Chinese history suggests.

One of the more perplexing dilemmas confronting the historian interested in the political economy of technological change is that the effect of political competition on technological progress is inherently ambiguous. Nations that worry about their political standing in the world are more likely to be subject to the "Sputnik effect," the discovery that a society has fallen behind in technological terms and is consequently threatened. From Peter the Great's Russia to Meiji Japan to the United States after the launching of the first Soviet satellite, nations have embarked on efforts to advance the techniques they employed primarily for political reasons. Some measure of competition between states is therefore healthy for technological progress. Unlike economic competition, however, political competition may degenerate into military expansion, war, and destruction, which negate any possible beneficial effects of political competition. There is thus clearly a subtle optimum point between the advantages and the hazards of competition between states.

Political fragmentation was thus not a sufficient condition for technological progress. In some cases (the city-states of ancient Greece, Islamic Spain, and the fragmented political units of medieval India come to mind) political decentralization led to more destruction than innovation. As in microeconomic theory, then, competition in and of itself does not guarantee efficiency. Nor was pluralism a sine qua non, since some progress obviously did occur within imperial Rome and imperial China. And yet in Europe, provided the units were able to preserve their independence and were not crushed by the economic burdens of defense, political fragmentation guaranteed that no single decision maker could turn off the lights, that the capriciousness or piety of no single ruler could prevent technological advances and the economic growth they brought.

CHAPTER NINE

China and Europe

The greatest enigma in the history of technology is the failure of China to sustain its technological supremacy. In the centuries before 1400, the Chinese developed an amazing technological momentum, and moved, as far as these matters can be measured, at a rate as fast as or faster than Europe. Many of their innovations eventually found their way to Europe, either by direct importation or by independent reinvention. Some of the Chinese achievements are summarized here.

1. Major improvements in the cultivation of rice revolutionized Chinese agriculture. Better control of the wet-field techniques allowed a tremendous expansion of rice cultivation in the south. The control of water through hydraulic engineering (dams, ditches, dikes, polders, walls) allowed the draining and irrigation of lands. Sophisticated sluice gates, pumps, and *norias* (water-raising devices that used a chain of buckets propelled by the stream itself to create a perfectly automatic pump) controlled the flow of water and prevented silting. It has been estimated that between the tenth and fifteenth centuries the number of water control projects in China increased by a factor of seven while population at most doubled (Perkins, 1969, p. 61).

2. The old Chinese scratch plow was replaced in the sixth century B.C. by an iron plow that turned over the sod to form furrows, and consisted of eleven different parts, some of which were adjustable to set the desired depth of the furrow. Later (in the eighth or ninth century) this plow was converted to be used in wet-field rice cultivation.

3. Seed drills, weeding rakes, and the deep-tooth harrow were introduced during the Sung (960–1126 A.D.) and Mongol (1127–1367 A.D.) dynasties. Chinese agriculture learned to use new fertilizers, such as urban refuse, mud, lime, hemp stalks, ash, and river silt. Insect and pest control used both chemical and biological agents with great success. A unique feature of Chinese agriculture was the large number of tracts and handbooks published dealing with agricultural technology. The *Annals* of the Sui dynasty (581–617 A.D.) mention the existence of eight treatises on veterinary medicine. Later, such

Figure 40. Fertilizing rice seedlings in medieval China, from the *Keng Chih* (Agriculture and Sericulture Illustrated), 1145.
Source: Thien Kung Khai Wu 1/15b.

masterworks as *The Essentials of Farming and Sericulture* and Wang Chen's massive *Treatise on Agriculture* (published in 1313) appeared. Chen's book contained 300 highly detailed illustrations, from which it was possible to reconstruct the implements depicted.

4. The Chinese led the Europeans by a millenium and a half or more in the use of blast furnaces, enabling them to use cast iron, and to refine wrought iron from pig iron. The casting of iron was known in China by 200 B.C.; it arrived in Europe at the earliest in the late fourteenth century. Although the exact dates of the begin-

ning of cast-iron production in China are unknown, there is no doubt that in the Middle Ages iron production in China far exceeded Europe's even on a per capita basis. This advantage rested on double-acting bellows that used pistons and were driven by waterpower; coal; refractory clays (to generate very high temperatures); and a superior knowledge of metallurgy.[1] One fortuitous factor was that Chinese

Figure 41. Chinese seed-drill used for sowing cereals, from the *Thien Kung Khai Wu* (Exploitation of the Works of Nature), 1637.
Source: Thien Kung Khai Wu 1/15b.

1. The Chinese succeeded, for instance, in making cast-iron bells, quite a difficult enterprise. In Europe, even after casting was known, bells were made primarily of bronze, since the Europeans did not recognize the special physical needs of bells (Rostoker et al., 1984).

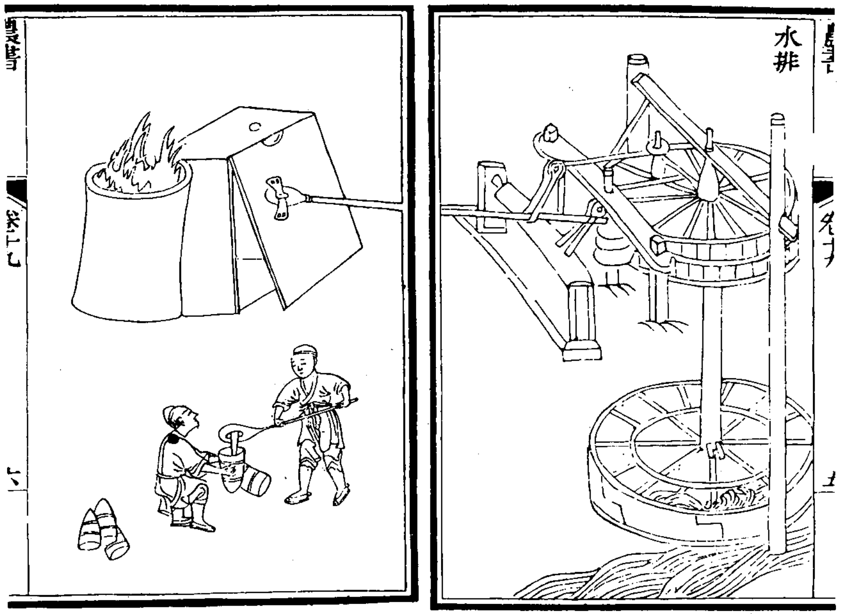


Figure 42. Water-driven blowing machine in Chinese smelting furnace, from the *Nung Shu* (Treatise on Agriculture) by Wang Chen, 1313. Note the use of the crank in the transmission mechanism.
Source: Joseph Needham, *Science and Civilisation in China,* Vol. 4 part 2, Cambridge University Press.

ores tended to be high in phosphorous, which reduced the melting point of iron and made casting easier. China also led the West in steel production, in which they used cofusion and oxidization techniques.

5. In textiles, the spinning wheel appeared at about the same time in China and the West—the thirteenth century (possibly somewhat earlier in China)—but advanced much faster and further in China. The Chinese applied central power sources to the spinning of yarns for which this application was relatively simple, such as the throwing of silk and hemp, and the spinning of ramie, a Chinese fiber plant. In cotton, the application of central power sources was not solved until the British Industrial Revolution, but the Chinese did manage early on to develop a small multispindle spinning wheel not unlike Hargreaves's spinning jenny. Sophisticated weaving equipment came even earlier: draw looms that wove complicated patterns in silk were used in Han times (around 200 B.C.) and were later used for cotton as well. Cotton was ginned by mechanical gins. By the end of the

Middle Ages, it appears that China was about ready to undergo a process eerily similar to the great British Industrial Revolution.

6. The adoption of waterpower in China more or less paralleled that in Europe. Reynolds (1983) has demonstrated that before the third century A.D., the Chinese primarily used water levers, primitive devices that create reciprocating motion by means of a pivot with a chute at its end that receives water, thus tipping it over. As early as the eighth century A.D. the Chinese were using hydraulic trip hammers, and by 1280 they were fully committed to the vertical waterwheel.

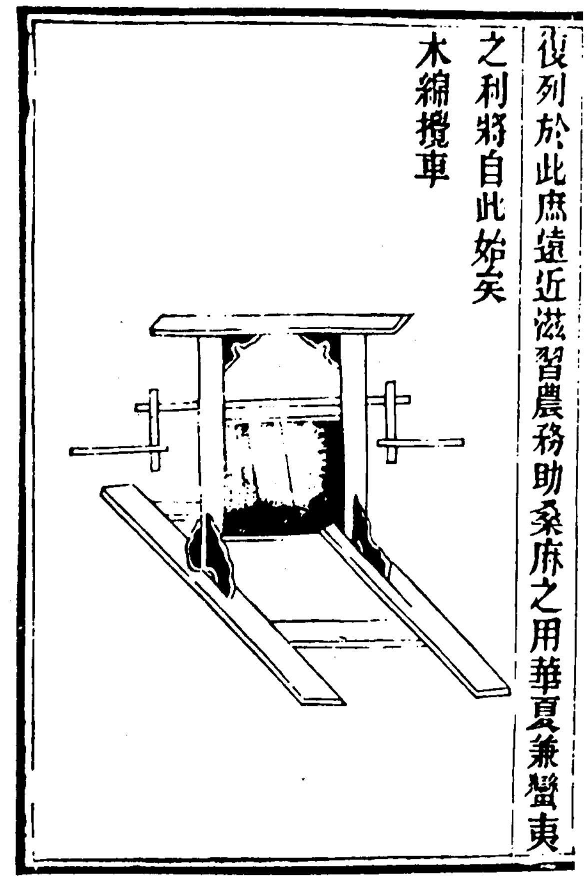


Figure 43. Chinese cotton gin, in use during the Yuan dynasty (thirteenth to fourteenth centuries).
Source: Nung Su, 1313.

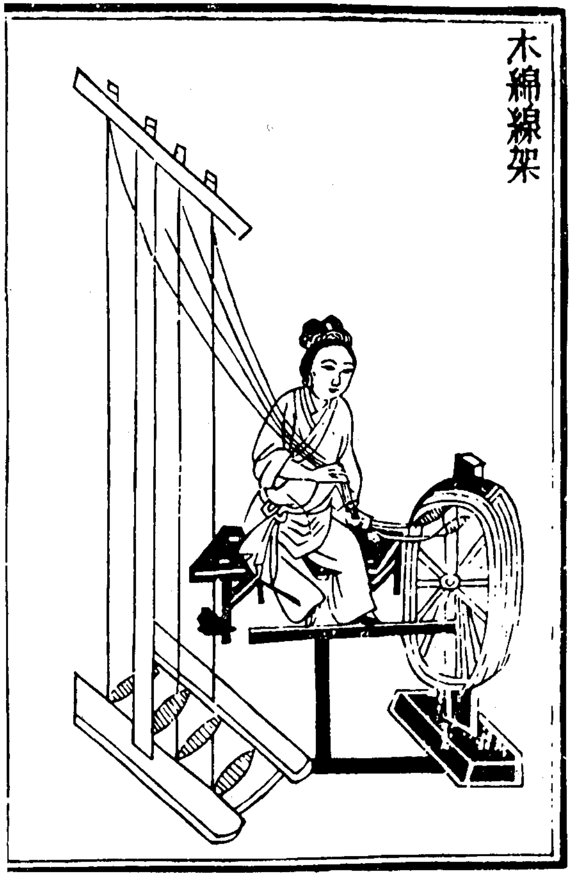


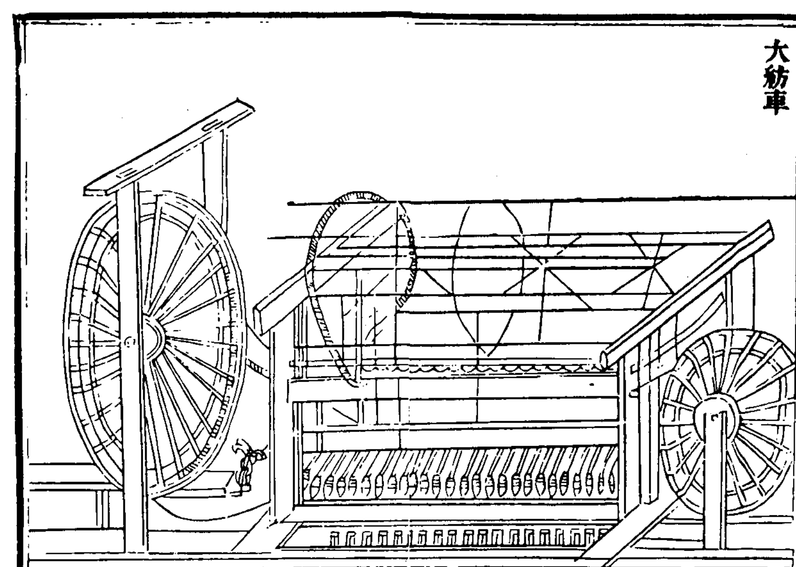
Figure 44. Spindle wheel for doubling (twisting together two separate yarns). The wheel is operated by a treadle.
Source: Nung Su, 1313.

7. For centuries it was thought that the Chinese learned to measure time from Westerners. This view was refuted by Needham and his associates, who showed that during the Sung dynasty, in the tenth and eleventh centuries, Chinese clockmakers built accurate and ingenious water clocks using escapement mechanisms (though their escapement mechanism was different from the verge and foliot that regulated the European weight-driven clock). The Chinese achievements in time measurement reached their pinnacle in the construction of Su Sung's famous clock in 1086 A.D. Su Sung's clock was probably the most sophisticated water clock ever built, measuring 40

ft. high, and displaying not only the time but also an impressive array of astronomical variables, such as the positions of the moon and the planets. Although it is not quite correct to see in the Chinese water clocks harbingers of the European mechanical clock, these instruments far exceeded in mechanical complexity, mastery of materials and mechanism, and accuracy of measurements anything that Europe had to offer circa 1100 A.D. (Landes, 1983, pp. 17–36).

8. Chinese achievements in maritime technology were also impressive. The Chinese invention of the compass (around 960 A.D.) is known to every schoolboy, but the compass was by no means their only success. In ship design and construction, the Chinese led Europe by many centuries. Their ocean-going junks were much larger and more seaworthy than the best European ships before 1400.[2] The Chinese ships were carvel built (planks laid out edge to edge), were equipped with multiple masts, and had no keel, sternpost, or stempost. The ships were built using a technique called bulkhead construction, which

Figure 45. Multiple spinning frame for ramie (hand-operated), used in medieval China. A larger version of this wheel was water-driven.
Source: Nung Su, 1313.



2. Marco Polo wrote in glowing terms of Chinese ships in the 1290s. The Moslem world traveler Ibn Battutah, echoed Polo's impressions half a century later. Elvin (1973, p. 137) notes that after 1000 A.D., foreign merchants preferred Chinese to foreign ships for travel.

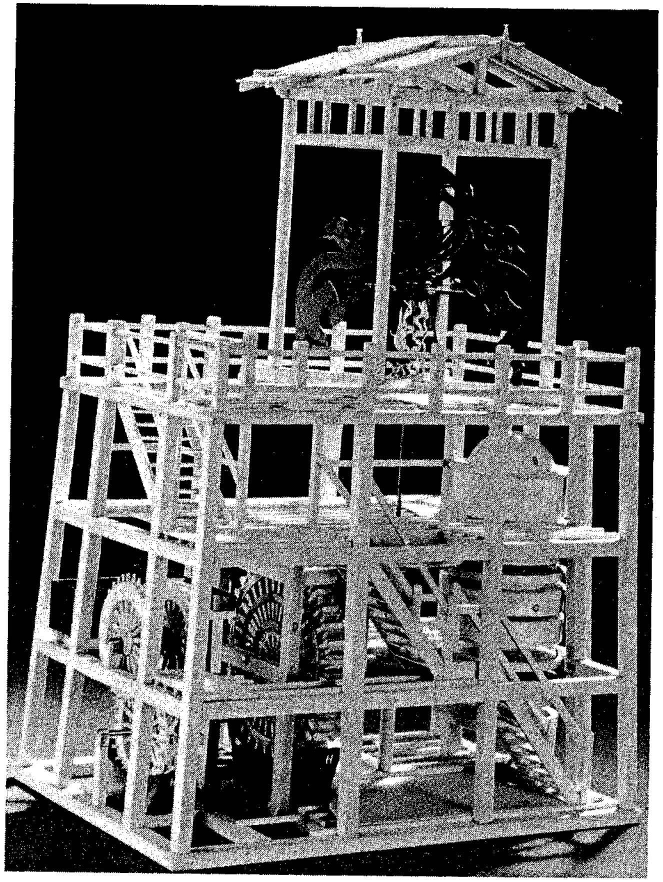


Figure 46. Model of the "Great Cosmic Engine" made by Su Sung in 1086. The clock had a mechanical escapement, but was turned by water power.
Source: Science Museum, London.

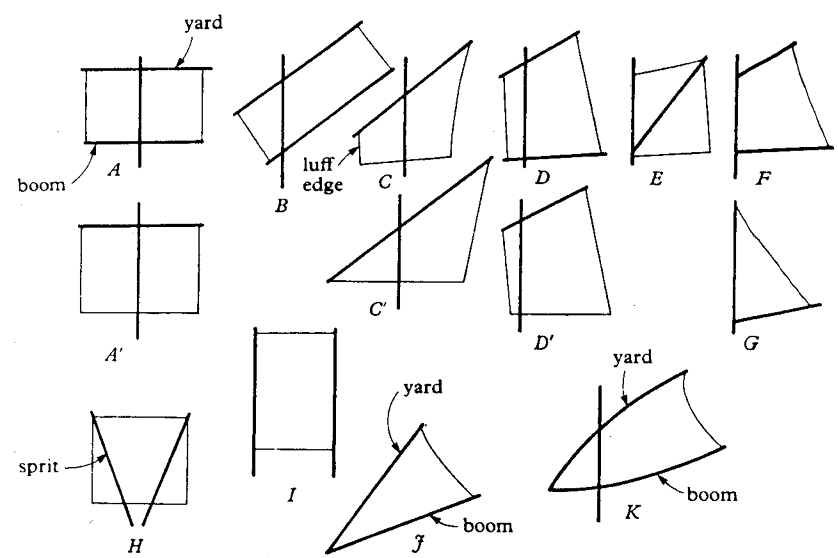
used watertight buoyancy chambers to prevent the ship from sinking in case of leaks. Needham suspects that this idea was inspired by the nodal septa of the bamboo stick (Ronan and Needham, 1986, p. 66). Despite its obvious advantages, the technique was not adopted in the West until the nineteenth century. Needham (1970, p. 63) concludes that Chinese ships were of "a much more solid construction than that found in other civilizations."

Chinese ships were also maneuverable to a degree not equalled elsewhere before the development of the triple-masted caravel in the mid-fifteenth century. As early as the third century A.D. the junks

were equipped with trapezoidal lugsails with fore-and-aft rigging, thus permitting the junks to sail to windward in much the same manner as the Western lateen sail. The Chinese also developed the sternpost rudder long before it appeared in Europe, an achievement all the more remarkable because Chinese ships had no sternpost properly speaking.[3]

9. The Chinese invented paper, an invention that took more than a millennium to reach the West. The invention was traditionally attributed to Tshai Lun, around 100 A.D., but modern scholarship has shown that paper was used several centuries earlier (Tsuen-Hsuin, 1985, pp. 40–41). Tshai Lun did pioneer the use of tree bark as a raw material. Paper was used for more than writing: high quality and durable paper found its way to the manufacture of clothing, shoes, and military armor. Paper money and wallpaper were used in medieval China, centuries before Europe, and as early as 590 A.D. the use of paper in Chinese lavatories was widespread (Needham,

Figure 47. Principal sail types. Sails of type D, D′, and E were the lug and sprit sails used on Chinese junks.
Source: Joseph Needham and Colin A. Roman, *The Shorter Science and Civilisation in China,* Vol. 3, Cambridge University Press.



3. An archeological find in 1958 unveiled a pottery model from the Han dynasty (first or second century A.D.) that clearly shows an axial rudder (Needham, 1970, pp. 257–58).

1970, p. 373). Printing probably began in the late seventh century.[4] At first the Chinese used block printing, a technique known as xylography that used a wooden plank carved in reverse, but in 1045 A.D. Pi Shêng invented moveable type made of porcelain. Metal moveable type was used in Korea in about 1240. Whether or not Gutenberg knew of these inventions is still in dispute; the evidence and logic are against it. Yet even if Europeans invented it independently, the triumph of Chinese technology stands undiminished.

10. Many other examples of Chinese precocity appeared between 700 and 1400 A.D. Genuine porcelain appeared in China in the T'ang period (618–906). In the early fifteenth century the famous porcelain pagoda of Nanking was built, nine stories (over 260 ft.) high, with outer walls cased with bricks of the finest white chinaware. The chemical industry in China produced lacquers, explosives, pharmaceuticals, copper sulfates (used as insecticides), and metallic salts. The idea of attaching a wheel to a stretcher and dispensing with the second bearer does not seem to have occurred to anyone in Europe before the twelfth century, whereas in China wheelbarrows were used from 232 A.D. on, and probably earlier. The Chinese drilled deep holes (up to 3,000 ft.) in the ground for the extraction of brine in Szechuan Province. Many centuries before Eilmer of Malmesbury, the Chinese used kites for manned flights. In military matters, the crossbow and the trebuchet were standard equipment in China centuries before their adoption in the West. The Chinese developed the modern horse collar in about 250 B.C., an invention that took a thousand years to find its way to Europe (Needham, 1965, pp. 311–12). In medicine the Chinese made important breakthroughs, some of which (like acupuncture) have been fully recognized in the West only during the last few decades. In the daily comforts and amusements of life, the West owes to China mundane but useful ideas such as matches, the umbrella, the toothbrush, and playing cards. The list goes on and on.

And yet China failed to become what Europe eventually became. At about the time we associate with the beginning of the Renaissance in Europe, China's technological progress slowed down, and ultimately came to a full stop. China's economy continued to expand, to be sure, but growth was mostly of the Smithian type, based on an expansion of internal commerce, monetization, and the colonization of the southern provinces. Some techniques that had been known fell into disuse, then were forgotten. In other cases great beginnings were not pursued to their full potential. The implications of this

4. The first known printed book was discovered in 1907 in a cave. It is a Buddhist text printed in 868 A.D. (Huard et al., 1969, p. 287).

failure for world history are awesome to contemplate. The Chinese were, so to speak, within reach of world domination, and then shied away. "China came within a hair's breadth of industrialising in the fourteenth century," writes Jones (1981, p. 160). Yet in 1600 their technological backwardness was apparent to most visitors; by the nineteenth century the Chinese themselves found it intolerable.[5]

The slowdown in the rate of technological change should not be interpreted as economic stagnation. Until the nineteenth century, Manchu China was able to feed a growing population, apparently without a decline in living standards. Yet this growth had none of the technological dynamism of the Tang and Sung periods. It is difficult to time the waning of China's technological progress with any accuracy. A gradual deceleration took place that by the nineteenth century resulted in unmistakable backwardness compared to Europe. In 1769 a British visitor to Canton, William Hickey, observed that, when shown how greatly they might benefit from adopting European technology, the Chinese "without hesitation admit our superiority with the utmost sangfroid, adding in favour of their own habits, 'truly, this is China's custom' " (cited in Jones, 1989, p. 16). An often-cited example of the gap between Western and Chinese technology is the Opium War between Britain and China in 1842, when superior technology allowed Britain to impose scandalous terms on a huge and proud empire.[6] The awareness that the West was gaining on them must have been a constant torment to informed Chinese officials long before that. The dilemma they faced was, as Cipolla put it, one of Hamletian doubt: should they copy the West or ignore it?

For centuries China chose to ignore. From the rise of the Ming dynasty in 1368 until the end of the nineteenth century, the Chinese economy expanded primarily through population growth, deforestation, commercial expansion, and ever growing intensification of agriculture, in an environment of increasingly stagnant technology.

5. One of the most amazing features of the great Chinese decline was that despite continuous contact with European civilization, it was difficult for them to admit how much they were falling behind Europe. A Chinese text written at the end of the eighteenth century claimed that apart from some progress in land surveying and irrigation, the achievements of the West had been confined to toys and oddities (Cipolla, 1967, p. 89). Yet from the middle of the sixteenth century on, the Chinese knew that Dutch and Portuguese guns, clocks, and instruments outperformed theirs. Even Western ships were regarded by the Chinese and Japanese as superior (Cipolla, 1965, p. 122).

6. As Headrick (1981) describes in detail, a handful of steam-driven British gunboats entered the Yang-Tseh River, and their powerful guns and unexpected ability to sail upstream created havoc among the Chinese, thus deciding the outcome of the war in Britain's favor.

The Chinese experience is a powerful counterexample to the Boserup-Simon theory that population pressure leads to technological progress.

Among the cases of Chinese technology that were actually lost or forgotten, that of time measurement is the most interesting, because of the technological spillover effects that the mechanical clock is alleged to have brought to Europe. By the sixteenth century, the Chinese had no memory of Su Sung's masterpiece. Nor did they ever manage to develop anything close to the weight-driven mechanism of the European clocks. The Jesuits arriving in China in the 1580s reported that Chinese time measurement was primitive, and craftily used clocks as a bait to the Chinese authorities to gain entrance into China. The Chinese expressed joy and wonderment over the novel device, but regarded it as a toy rather than a useful instrument.

In ocean shipping, China's decline relative to the West was abrupt. Less than a century after the great voyages of Cheng Ho, the Chinese shipyards were closed and seagoing junks with more than two masts were forbidden. The technology of building large, seaworthy junks capable of long-distance journeys disappeared from China. In the iron industry there is less direct evidence of technological decline. In 1690 there is some evidence of a cold blast being applied in steel making, a sort of proto-Bessemer converter. Yet even an admirer of Chinese technology like Needham is forced to concede that "in modern times the world has seen China as a culture of bamboo and wood" (Needham, 1964, p. 19). Or consider the *sao chhê*, a silk-reeling machine that was used in China as early as 1090 A.D. (Needham, 1965, pp. 2, 105–8). Yet by the middle of the nineteenth century raw silk, which comprised about 35 percent of China's export, was entirely hand reeled, yielding a product of uneven quality that had to be rereeled in Europe (Brown, 1979, p. 553).[7] Or consider coal, which had been mined in China since medieval times and was reported with some amazement by Marco Polo. By the nineteenth century Chinese coal mining was primitive, took place in shallow mines, and was devoid of any machinery for ventilation, pumping, or elevation (Brown and Wright, 1981). Between the medieval era and the modern age something was lost in China.[8]

Equally striking is the inability of Chinese technology to press forward in areas in which they were very close to making a breakthrough. Moveable type, for instance, did not catch on in China, where wooden block printing continued to dominate. A likely explanation is that moveable type was less suitable to an ideographic script than to the simpler alphabet of the Western world.[9] But how can we explain the failure of Chinese spinners to develop a proper spinning jenny? As Chao (1977) has pointed out, multispindle spinning, adopted for ramie, never found an application to cotton, where small spinning wheels spun three or four spindles, but never more. The critical element in Hargreaves's spinning jenny, missing in Chinese cotton spinning technology, was the draw bar, a device that imitated the human hand in drawing out a large number of rovings at the same time. It seems hard to believe that such a relatively simple device never occurred to some ingenious Chinese, but if it did, there is no sign of it. Similarly, the Chinese developed a treadle loom in the Ming period (1368–1644), but after that weaving remained unchanged until the end of the nineteenth century. Something like the flying shuttle, a simple device that increased the productivity of weaving by a large factor, never seems to have occurred to them.

In many other areas, the Chinese were unable to press their advantage. Consider, for example, military technology. In the tenth century A.D. the Chinese used gunpowder in rockets and bombs. In spite of their knowledge of explosives and their superiority in siderurgy, they apparently had to learn to use cannon from the West (in the mid-fourteenth century) and they failed to develop Western military techniques any further.[10] When the Portuguese reached China in 1514, the Chinese were deeply impressed by Portuguese muskets ("Frankish Devices") and swiveling naval cannon and adopted them readily (Needham, 1981, p. 44). Yet the Chinese were unable to keep up with the continuous progress made in firearm technology in the West. In the seventeenth century, the Ming emperors had to ask the Jesuits in China to aid them in purchasing cannon from Macao to defend their country against the Manchu Mongolians. In the 1620s, Chinese officials repeatedly advised the adoption of Western cannon by the Chinese army. As late as 1850 the Chinese army still used

7. It is possible, as Kuhn (1988, pp. 400–4) has maintained, that there was little gain in productivity by adopting mechanical reeling except for the increased uniformity of quality. Yet by the end of the nineteenth century, China adopted the Western silk-reeling machinery.

8. The decline of the Chinese iron industry has been ascribed in part to the Mongol conquest of the thirteenth century and the reduced military demand for iron by the Yuan dynasty (1264–1368), whose military technology was not iron based.

9. In Korea, where moveable type first appeared, fifteenth-century printers invented a phonetic alphabet known as *Hangul*, which could have made printing far easier. Yet vested interests insisted on clinging to the old Chinese characters, and consequently few books were printed in Korea until the nineteenth century (Volti, 1988, p. 141).

10. It is possible that someone in Szechuan province actually invented a cannon in the eleventh or twelfth century. Yet there is no evidence that firearms were used in China before they arrived from Europe. I am grateful to Prof. Lynda Schaffer of Tufts University for communicating this information to me.

weapons of sixteenth-century vintage, and only the pressing need of civil war during the Taiping Rebellion (1851–64) compelled them to buy modern firearms in the West (Hacker, 1977).

In waterpower technology progress never quite stopped altogether, but their accomplishment "does not compare to the European accomplishment, particularly in the period from the eleventh to the sixteenth century" (Reynolds, 1983, p. 116). In agriculture, the Chinese came into contact with new crops from the American continent through Portuguese traders and Chinese settlers in the Philippines. Their record in adopting these crops is mixed: some crops, such as sweet potatoes and peanuts, which thrive on marginal soils, were widely cultivated. But the major dryland staples, such as potatoes and corn, were adopted only slowly, in spite of the advantages of these crops (Perkins, 1969, p. 47; Bray, 1984, p. 458).[11] A specialist in ecological history, (Jones, 1981, p. 171) judges that Chinese progress in agriculture "in no way compares with Europe's record of technological achievements." Another historian of Chinese agriculture (Chao, 1986, p. 195) states flatly that "the invention rate [in Chinese agriculture] declined sharply after 1300 and finally came to a complete halt after 1700." Opportunities for improvements were missed. European piston pumps were brought to China, and would have been of great value in the irrigated farming regions of northern China, such as Hunan and Shansi provinces. They were rarely used however, presumably because of the high cost of copper. But even a simple device such as the Archimedes screw pump, which was brought to China by Jesuits and which the Chinese at first showed some ingenuity in adopting, was little used because of the high cost of metal (Elvin, 1973, p. 303). How it came to pass that a society that pioneered metallurgical technology in the Middle Ages had to forego the adoption of simple and useful gadgets because of the cost of materials is still a mystery. Even in the dissemination of technical knowledge there appears to have been retrogression: the great technical encyclopedia, the *Thien Kung Khai Wu* (Exploitation of the Works of Nature), written in 1637 by Sung Ying Hsing, ("the Chinese Diderot") provided an excellent summary of Chinese technology from weaving to hydraulics to jade working. The work was destroyed,

11. Corn had the advantage that it could be grown in relatively barren mountains, which had low opportunity costs. The same is true a fortiori for potatoes, which are labor intensive and provide a high yield per acre, making them an attractive crop for high-density populations. The alleged reason these crops failed to be adopted more widely in China is that the Chinese disliked their taste to the point where "eating potatoes is considered to be an act of desperation preferable only to starvation" (Perkins, 1969, p. 48) and "positively disliked [maize] . . . ," regarding it a "last resort" (Bray, 1984, p. 458).

probably because of the author's political views, and has survived only thanks to a Japanese reprint.[12] Wang Chen's great *Treatise on Agriculture* was published in 1313, but by 1530 there was only one surviving copy.[13]

It seems tempting to explain the waning of China's technology after 1400 as merely a relative change. The time at which China's technological change slowed down happened to coincide roughly with the century in which Europeans learned to cast iron, to print books, and to build ocean-going ships. Some historians (e.g., Hucker, 1975, p. 356) have tried to explain China's backwardness in modern times by arguing that the technological slowdown in China after 1400 was quite natural, and it was Europe's spectacularly fast advance that must be explained. But this relativistic view of Chinese history is not wholly satisfactory. First, China's lack of progress after 1400 is striking not only in light of Europe's success, but also compared with its own performance in the previous centuries. Second, such a comparative approach really only begs the question further. The European experience seems to suggest that nothing succeeds like success: upon the slow but relentless progress of the early Middle Ages, the engineers of the Renaissance built further achievements, which in their turn paved the road for the inventors of the Industrial Revolution and for the complete technological superiority that Europe had attained by 1914. Why does such a cumulative path-dependent model not work for China? After all, the technological problems the two civilizations had to solve—how to secure the necessary fertilizer for arable farming, how to produce textiles, how to utilize sources of kinetic and thermal energy and how to secure the supply of high-quality materials for tools and construction—seem similar. The solutions were indeed so similar that Needham has repeatedly argued for the transmission of innovations from the leader (China) to the follower (Europe).

In a related vein, Bray (1986) has argued that China's apparent failure is to some extent an optical illusion. Technological change in

12. The many beautiful and illustrative pictures of mechanical devices in the work clearly refute Cipolla's (1967, p. 33) generalization that the difference between the European and the Chinese environment was exemplified by Francesco di Giorgio and Leonardo Da Vinci drawing mills and gears, whereas their Chinese counterparts drew flowers and butterflies.

13. A comparison between two agricultural treatises published by the government half a millenium apart highlights the change. The *Nung Sang Chi Yao,* dating from 1273, is a practical handbook, providing useful information and guidance on how to grow the right crop in the right soil. The *Shou Shih Thung Kao,* published in 1742 and distributed throughout China, is largely a piece of imperial propaganda aimed at the glorification of the emperor and stressing the ceremonial over the practical (Bray, 1984, pp. 70–74).

the labor-intensive rice economies simply took a form that was different from the labor-saving inventions of Europe. Population growth led to an intensification of agriculture through multicropping and other labor-intensive techniques. Bray criticizes "Eurocentric" models of historical change as biased against the kind of changes that were occurring in the Orient. Up to a point, there is merit in her views. Wet-rice fields achieved yields per acre far in excess of anything in the West. Yet output *per person,* the ultimate arbiter of economic success, remained at best stable until 1800, after which it succumbed to population pressure. The difference between the European and the Chinese experiences can be illustrated by the fact that between 1750 and 1950 Europe's population grew by a factor of 3.5 while China's grew by a factor of 2.6. Yet Europe fed itself with ease and managed to create a vast surplus above subsistence, improving living standards beyond the wildest dreams of earlier ages. In the rice economies of Asia and their wheat-producing neighbors, poverty and malnutrition became increasingly frightful. Europe and Asia differed not because one was capitalistic and one was not, or because one had developed larger-scale cereal- and- livestock farms that lent themselves better to mechanization than small-scale rice paddies. The real difference was that the West, or at least a significant part of it, was technologically creative and managed to stay so for a longer period than any other society. Unlike the Chinese, the Europeans did not just save land and capital, using labor more and more intensively. European inventions were at times labor saving, at times land saving, at times neutral. Their main feature was that they produced more and better goods.

The immense difficulty of the question of why China fell behind is illustrated by the obvious weaknesses of some of the solutions that have been suggested. Many hypotheses have been proposed to explain the failure of specific innovations to emerge in China. Chao (1977, ch. III), for example, explains the failure of China to employ a jenny-type spinning machine in its cotton industry by arguing that such a device would require three persons to work simultaneously, making it unsuitable for household production. The argument is unpersuasive, but even if it were correct it would explain but one aspect of a much larger problem.[14] Similarly, the decline of ocean shipping has been blamed on the political victory of the antinaval clique at the Imperial Court after 1430. In agriculture, the lack of fertilizer has been seen as a cause for the stagnation of productivity

14. Apart from the fact that in Britain the spinning jenny was originally intended for and used in household production, Chao wholly ignores the large-size businesses in China that manufactured iron, ships, tea, and textiles, using hired labor. A labor-exchange system existed even in rice farming (Bray, 1986, p. 120).

relative to Europe. Such an hypothesis merely begs the questions, however, because it fails to explain why the Chinese were unable to increase livestock production through fodder crops, as was done in Europe, or why they were so slow in adopting corn or potatoes. In her monumental work on Chinese agriculture, Bray points out that wet-rice cultivation did not lend itself to mechanization because of its small optimal production scale and the difficulty of developing machinery that would replace labor in the wet fields without reducing yields (Bray, 1984, p. 613). But how does this theory explain the lack of progress of agriculture in the dry-field cereal economy of north China? Jones (1981, p. 221) emphasizes the importance of internal migration, which operated as a safety valve. The opportunities of the southern forest lands drew entrepreneurs away from the technological frontiers of Sung times, "setting Ming and Manchu on a course of static expansion." But in the West colonization and internal migration do not seem to have interfered with technological innovation. In the twelfth and thirteenth centuries, when western Europeans colonized the areas east of the Elbe River, progress seems to have been as rapid as ever.

An ambitious theory to account for the Chinese decline has been suggested by Elvin (1973), who tried to explain the stagnation of the Chinese economy in terms of a "high-level" equilibrium trap. Elvin's model assumes that the opportunities for technological change in agriculture were limited, and that population growth shifted demand from nonagricultural goods to agricultural goods. Moreover, he suggests, population pressure reduced the supplies of indispensable materials, such as wood and metals, which reduced the opportunities for technological change. It is interesting to note that this approach is diametrically opposed to those theories in which technological change is considered a "response" to the "challenge" of necessity and scarcity. Instead, in this view scarcity impedes technological change. Elvin's theory, however, is hard to square with other facts, among them the sharp decline in population due to the epidemics that devastated China between 1580 and 1650 and reduced population by 35 to 40 percent by Elvin's own estimates (ibid., p. 311), though other sources estimate the decline to have been smaller. Furthermore, he assumes that population growth led to a falling surplus and per capita income, and therefore to declining demand for manufactured goods to explain why "profitable invention became more and more difficult" (ibid., p. 314). According to Perkins (1969) and Gernet (1982), the significant decline in income or agricultural output asserted by Elvin did not occur. Moreover, the argument involves circular logic, as successful invention would have raised real incomes and thus made itself profitable. Finally, and most importantly, Elvin confuses *total* with *per capita* income: the determinants of market demand are both income per capita and the number of capita in the market. At least on the latter account, successful invention in China must have been more profitable than Elvin imagines, because population went from 75 million in 1400 to 320 million in 1800. Finally, Elvin's argument that demand grew mostly in the agricultural sector whereas the technological opportunities were in manufacturing ignores the linkages between nonagricultural technology and food supply through improved transportation and industrially produced implements. It also fails to explain why Chinese farmers were so slow to adopt steel-tipped plows or piston-driven water pumps in this period, or why they were reluctant to adopt a labor-intensive, high-yield crop, such as potatoes.

The problem seems so huge that it is tempting to resort to some exogenous but relatively simple theory to explain a massive societal behavior change. Physiological or dietary factors thus appear an attractive alternative to social explanations. China's ever-increasing dependency on rice as its main source of food could be related to protein deficiencies, particularly in view of the low consumption of meat and the total absence of dairy products. The shift from wheat to rice as the center of gravity of Chinese society moved southward may have been associated with a decline in average nutritional status. A telling comment of travelers was that the southern Chinese were substantially shorter than the northern Chinese, whose diets depended less on rice. Whether or not the increasing dependency on rice can be correlated with increased protein deficiency remains unclear, but the possibility seems worthy of further investigation.[15] Malnutrition need not have been confined to children, and it is possible that the overall level of food production in parts of China did not keep up with the rapid growth of population, leading not to mass starvation so much as to the lethargy and lack of energy characteristic of undernourished populations. An interesting related point is made (but not pursued) by Jones (1981, pp. 6–7), who notes that when the demographic center of gravity of China shifted south, much of the farm work was carried out in warm standing water and human feces were used as fertilizer. This led to an incidence of parasitic disease unparalleled in Europe. Debilitating endoparasitic infection—especially schistosomiasis, which is closely associated with wet-paddy cultivation—may have devastated the energetic and adaptable labor force required for sustained technological change. Explanations of macrohistorical events based on human physiology may seem farfetched and speculative. But the connections between changes in human biology and economic history have only recently begun to be explored, and future research will have to examine this issue in detail.

15. Polished rice contains relatively small quantities of protein (seven percent), though its protein tends to be of a high quality. Unmilled ("brown") rice is richer, but because it is more difficult to cook and chew, it is less popular, especially for infants. Without knowing more about the quantities consumed by infants, any inferences concerning infant protein deficiency syndrome (IPDS) must remain speculative. The cereals in the Chinese diet were supplemented by fish and soya products, which provided protein supplements. In the dense agricultural regions of the south, however, the dependence on rice diets may have caused significant nutritional deficiencies.

A popular explanation for China's backwardness has been that the Chinese frame of mind was somehow not suited to scientific and technological progress. In a famous essay entitled "Why China Has no Science," published in 1922, the Chinese philosopher Fêng Yu Lan argued that Chinese philosophy was inherently inward looking. It was the soul, not the environment, that the Chinese wished to conquer. "The content of [Chinese] wisdom was not intellectual knowledge, and its function was not to increase external goods," wrote Fêng Yu Lan (cited in Needham, 1969, p. 115). Confucian philosophy viewed the purpose of scholarship and public administration as the maintenance of harmonious relationships within society and an equilibrium between human beings and their natural environment. But the argument in this crude form is untenable. Before 1400 China not only had a science, but its science and technology were in many ways superior to those of the West. The Chinese never hesitated to put their inventions to use, creating the same kind of free lunches the West learned to generate in the Middle Ages. Even after 1400, there seems to be little evidence of any reluctance by the Chinese to tamper with their environment. In the eighteenth century, massive deforestation and colonization of southern woodlands took place, leading to soil erosion and environmental traumas typically associated with industry and rapid expansion. The worst error one can make in this area is to attempt to explain China as if it were an unchanging entity. The question most in need of an answer is not why China differed from Europe, but why China in 1800 differed from China in 1300.

Between the one extreme position (that China's technology was backward because of an aversion to manipulate and exploit nature) and the other (that there was no difference between China and the West), it is possible to occupy a middle ground. The difference between Chinese and European civilizations was one of degree, a degree that rose after 1400, when Europe's attitudes to the material world grew increasingly exploitative. Both civilizations believed in the right to use nature to satisfy human material needs and improve the human lot whenever possible. But the history of technology is not only the tale of taking advantage of opportunities, it is also one of creating them. Here the aggressiveness of the West and its belief in unbridled and unconstrained progress differed substantially from the more moderate Eastern view. Needham (1975, p. 38) cites with approval Lynn White's essay "The Historical Roots of our Ecological Crisis" (repr. in White, 1968), in which he places the responsibility for the ecological crisis squarely on Western religion. The belief in a personal God looking with approval upon the relentless exploitation of material resources was lacking in China. Instead, Chinese (primarily Taoist) natural philosophy sought to find an equilibrium between humanity and the physical environment. Neither the submission of humans to overwhelming forces of nature, nor their unquestioned dominance over nature in the anthropocentric view held by Western civilization was prevalent in China. Rather, a steady state in which a cooperative, harmonious relationship between nature and humanity prevails was held to be ideal. "The key word is always harmony," writes Needham (1975, pp. 35–37), "to use nature it was necessary to go along with her . . . there was throughout Chinese history a recognition that man is a part of an organism far greater than himself."

Even in this modified form, less extreme than the Fêng view, the importance of the influence of natural philosophy on technology has been disputed.[16] A possible scenario is that there was a gradual change in the Chinese attitude toward nature after 1400 or so. Some scholars believe that the rise of a "sterile conventionalized version of neo-Confucianism" may have led to a replacement of the vigor of the Tang and Sung periods by an introspective culture and political lethargy that was reflected in many branches of science and technology (Ronan and Needham, 1986, p. 147; Gille, 1978, pp. 466–67). An important example of this school was Wang Yang Ming, a sixteenth-century philosopher who taught that nature was but a derivative of the human mind and that outside the mind there are no principles or laws. Such a theory, had it been widely accepted, could help explain the slowdown of Chinese science, although Wang also taught that knowledge is nothing unless it is put into practice (Harrison,

16. The key word in Chinese is *wu wei*, which encapsulates Taoist wisdom. In Bertrand Russell's words, it means "production without possession, action without self-assertion, development without domination." Max Weber contrasted Confucian rationalism, which implied rational adjustment to the world with "Puritan" rationalism," which implied rational mastery of the world. Some modern writers, including Elvin (1984) and Jones (1981), tend to be rightfully skeptical of this simplified view of Chinese economic history, pointing to the contrast between Chinese farming, which made heavy use of irrigation, river control, terraced slopes, and similar manipulations of nature, and European rain-based farming.

1972, p. 336). In any event, metaphysical idealism never became dominant in Chinese thinking, and it seems of little help in explaining the slowdown in technology in post-medieval China.

An interesting difference between Chinese and Western thinking concerns logic. Unlike the West, China failed to develop a system of formal logic. Despite their achievements in algebra, the Chinese do not appear to have been interested in rigid logical structures such as "something is either A or not A." Instead, they were attracted to what we would today call "fuzzy logic," a rather recent branch of mathematics in which concepts such as "perhaps" or "somewhat" are allowable. Needham (1975, pp. 31–33) maintains steadfastly that this peculiarity in Chinese thinking had no effect on scientific developments and believes with Francis Bacon that "logic is useless in scientific progress." Clearly, however, that statement is one by which Bacon would not have liked to be remembered. His objection to mathematics as a tool of scientific inquiry was ignored by Galileo, Descartes, Newton, Leibniz, and almost every other leading scientist of his time.[17] In a similar vein, Hartwell (1971) has argued that Chinese logic was based on historical analogy rather than on the hypothetico–deductive method of the West. He admits that inference by analogy and induction can lead to successful engineering discoveries, but transformation of the modern world using inductive methods would have taken "several millennia" rather than "three or four centuries" (ibid., pp. 722–23).

The question is not whether the lopsided development of Chinese mathematics impeded modern science, but whether it had strong repercussions on technology. Although we have seen that mathematics began to penetrate the work of Western engineers in the seventeenth century, it seems exaggerated to attribute all of the divergence of Western and Eastern technologies to it. The question raised by Fêng is thus doubly ill-posed for our purpose: China *had* a science but it eventually became "mired in an obsolete traditionalism" (Gille, 1978, p. 467). It was also a technological leader for many centuries, but lost its leadership after 1400 to the West. However, the nexus between technology and science is much more subtle than earlier writers seem to assume. Needham and other writers on China may have overestimated the impact that Western science had on Western technology before the mid-nineteenth century. The inference that the West had a modern science and *ergo* had superior technology is unwarranted. We simply do not know what kind of logic was em-

17. It is interesting to observe that Needham changed his mind on this point. In a paper first published in 1964 (1969, p. 117), he wrote that "in Western Europe alone there developed the fundamental principle of the application of mathematized hypotheses to Nature, the use of mathematics in putting questions."

ployed by the unknown men and women who helped advance technology in the centuries before the Industrial Revolution. The correlation between scientific and technological development does not imply causation. The same kind of factors that brought about the growth of science in the West were also responsible for its technological progress. Fêng's question should have been why China lost its lead in science, not why China had no science at all. Yet the answer to that question, important by itself, is not necessarily the same as the answer to the question why China lost its lead in technology, which is my main concern here.

It seems thus all too readily assumed that China's technological backwardness relative to the West is attributable to the undeniable progress in European relative to Chinese science after 1500. Tang (1979) believes that Chinese agricultural technology ran into diminishing returns in the absence of scientific breakthroughs. But science explains little of the increase in European agricultural output in the century between 1750 and 1850, when population increased by close to 100 percent without any visible indications of diminishing returns. Tang (ibid., p. 9) argues that "the sort of tinkering and experiment and discovery by trial-and-error in which the Chinese got their early technological jump could not have led to a cumulative systematic knowledge base capable of advancing itself and sustaining an endless flow of ever more advanced applications." Yet such trial and error tinkering was precisely how Europe established its technological lead over China between 1500 and 1800. The differences between Europe and China in this regard are not overwhelming. Needham (1959, p. 154n) remarks that those who point out that China never produced men like Galileo or Descartes forget that China did produce men like Agricola and Tartaglia.

In terms of social explanations, no fully satisfying interpretation has been proposed. Regrettably, the planned eighth volume of Needham's *Science and Civilization in China,* in which he promised to deal with the social factors determining technological change, has not appeared. In an essay originally published in 1946, Needham (1959, pp. 166–68; 1970, p. 82) suggested that the main cause of China's failure to develop a European-style technology was the failure of merchants to rise to power in China. In Europe, Needham maintained, technology was closely related to merchants, who financed research in order to develop new forms of production and trade. In Chinese society, dominated by its imperial bureaucracy, little or no private profit could be gained from mechanics, ballistics, hydrostatics, pumps, or other forms of applied knowledge. Economic historians such as Rostow (1975, pp. 19–21) have found this view impossible to accept. Modern research suggests that Needham's premise

is incorrect. Metzger (1979) has pointed out that in the Ming-Qing period (1368–1911), the social status of commoner groups, among which merchants were predominant, improved. Moreover, whatever the role of mercantile capitalism in the development of Europe's technology, it is not clear that the political position of European merchants was on the whole much more powerful than that of their counterparts in China, where trade and commerce were as well or better developed. Finally, the whole notion that research was "financed" seems oddly anachronistic.

In more recent writings, Needham seems more inclined to embrace views closer to those of Jones's and others (cf. Needham, 1969, pp. 120–22). China was and remained an empire, under tight bureaucratic control. European-style wars between internal political units became rare in China after 960 A.D. The absence of political competition did not mean that technological progress could not take place, but it did mean that one decision maker could deal it a mortal blow. Interested and enlightened emperors encouraged technological progress, but the reactionary rulers of the later Ming period clearly preferred a stable and controllable environment. Innovators and purveyors of foreign ideas were regarded as troublemakers and were suppressed. Such rulers existed in Europe as well, but because no one controlled the entire continent, they did no more than switch the center of economic gravity from one area to another.

Perhaps the best example of what a regressive government could do comes not from technological change, but from Chinese geographical exploration, which was completely halted after 1430 due to a decision by the imperial court. No single European government could have stopped exploration: when the Portuguese lost the initiative in their overseas empire after 1580, the Dutch and the English were all too happy to assume their duties. More was involved, however. The exploration and exploitation of the new territories by Europeans was a joint venture between private and public enterprise. Why did China not produce an organization like the East India Company—say, a West Europe Company—after 1430? The answer is not only that the government prohibited the construction of large ships, but more fundamentally that the Chinese lacked demand for foreign goods. Europeans had always wanted things that only the Orient could produce; the Oriental empires had little interest in Europeans and their products. All this changed in the middle of the nineteenth century when both Japan and China discovered the military capability of Western weapons. Even then, Japan adopted European technology rapidly lock, stock, and barrel, while China tried for decades to import European arms while preserving its old social and economic institutions (Hacker, 1977).

Can a similar argument be applied to technological change? Could it be that the Chinese simply lost interest? In other words, was the difference between Europe and China after 1400 one of preferences, of attitudes toward technological change and its consequences? Needham (1969, pp. 117–19) has argued that although a "stagnant" China never truly existed, there was a certain "spontaneous homeostasis" about Chinese society, which he contrasts with Europe's "built-in quality of instability." Chinese society in this view had an endemic preference for self-regulation, a set of feedback mechanisms that ensured the ergodic motion of Chinese technology. Although there is a certain attractiveness to a view that reduces the difference between East and West to the difference between an equilibrium and a disequilibrium model, as stated it is more a description than an explanation. The statement could be interpreted, however, to mean that on average the Chinese somehow valued stability more than the Europeans did. East and West may have differed in their aversion to change and in their attitudes toward the rate at which change occurs.

Why should this be so? As I argued earlier, technological progress is a positive-sum game, with winners and losers. Although by definition total gains exceeded total losses, the adjustment costs and possible political unrest may have constituted a price that some societies were not willing to pay. The evaluation of the social costs of technological progress is difficult; they could differ immensely from place to place. What may have appeared as a very cheap lunch in the West may have been regarded as unacceptably costly in China. A decline in the rate of technological change in China could thus be attributed to a change in social preferences in the direction suggested by Fei (1953, p. 74), who emphasized the desire of Chinese society to avoid the social conflicts often entailed by technological changes. Another possibility is that a shift in the distribution of power and influence within society in favor of more conservative groups took place. Here, perhaps, is one crucial difference between Europe and China. Luddism and outright resistance to technological progress did occur in China, though the number of documented cases is small (Elvin, 1973, p. 315).[18] Potential innovators may have sensed the dangers and shied

18. In 1870, a Chinese silk weaver by the name of Chen Chi-yuan built a steam-driven silk-spinning mill that he had copied from the French in Annam (Indochina). A protest from workers who felt that their livelihood was threatened led him to modify the machine into a smaller and cheaper unit that could be more readily acquired. Not many cases were necessary for the threat of violence to deter potential innovators. Xenophobia may have had as much to do with resistance to innovation as the protection of vested interests.

away from novel ideas, often associated with Western influence.[19] The guilds in China remained powerful, and have been blamed for blocking the adoption of improved technologies in mining, transport, soybean-oil pressing, and silk reeling (Olson, 1982, p. 150). One author concludes that "market forces could not overcome vested-interest opposition and ensure success even in the transfer of a demonstrably superior technology" (Brown, 1979, p. 568). In China's past, technological progress had typically been absorbed by the political status quo, without disturbing the existing order. Radical technological changes threatening the balance of power were carefully avoided.

The difference between China and Europe was that in Europe the power of any social group to sabotage an innovation it deemed detrimental to its interests was far smaller. First, in Europe technological change was essentially a matter of private initiative; the role of rulers was usually secondary and passive. Few significant contributions to nonmilitary technology were initiated by the state in Europe before (or during) the Industrial Revolution. There was a market for ideas, and the government entered these markets as just another customer or, more rarely, another supplier. Second, whenever a European government chose to take an actively hostile attitude toward innovation and the nonconformism that bred it, it had to face the consequences in terms of its relative status in the economic (and thus, eventually, political) hierarchy. Moreover, the possibilities of migration within Europe allowed creative and original thinkers to find a haven if their place of birth was insufficiently tolerant, so that in the long run, reactionary societies lost out in the competition for wealth and power.

Before 1400, the state played a far more important role in generating and diffusing innovations in China than it did in Europe. The government, for instance, deliberately attempted to monopolize the measurement of time and the calendar. As Landes (1983, p. 33) put it, "In China the calendar was a perquisite of sovereignty, like the right to mint coins. . . . The Emperor's time was China's time." Su Sung's great masterpiece was built by and for government officials at the emperor's instructions. In the great agricultural expansion of the Middle Ages, government played a central role in the coordination of hydraulic projects and the dissemination of technical infor-

19. In 1887, an American newspaper reported that "over a thousand telegraph poles of one line in China have been pulled down by the people, who say the telegraph is a diabolical European artifice" (cited in the *International Herald Tribune*, Aug. 29–30, 1987).

mation. Officials wrote and published books on farming and promoted the adoption of faster-ripening and more drought-resistant strains of rice, especially the Champa varieties introduced from Southeast Asia early in the eleventh century. Wang Chen and Hsü Kuang Chhi, the authors of massive treatises on farming, were government bureaucrats. As early as the Han period (221 B.C. to 220 A.D.) the government provided peasants with the capital they needed for agricultural improvements, including tools and draft animals, and actively promoted the use of better plows.[20] A millennium later, the Sung government offered financial incentives to farmers to invest in improvements (Bray, 1984, pp. 597–99). The government also played a major role in the development of transport technology and in the diffusion of medical knowledge. The Chinese imperial government established huge state-owned iron foundries that promoted the use of iron implements. Even in textiles, the Yuan and early Ming governments played a very active role in the diffusion of the use of cotton (Chao, 1977, pp. 19–21).[21]

At some point, government support was withdrawn. Europeans trying to develop Chinese mining in the mid-nineteenth century found that is was an impossible task without state support, but that such support did not exist. Chinese officials simply were not interested in technological advances (Brown and Wright, 1981, p. 80). During the Qing (Manchu) dynasty (1644–1911), the Chinese government ceased almost entirely to provide any kind of public services (Jones, 1989). It did not provide the usual elements of the infrastructure necessary for economic development, such as standardized weights, commercial law, roads, and police. In many areas, the private sector managed to substitute for the public sector in providing these services, but in technological progress this could not be done. Jones (ibid., p. 30) concludes that "China's political structure did not establish a satisfactory legal basis for economic activity." It would be more appropriate to restate this proposition in terms of change. Routine economic activities seem to have been carried out reasonably well, as long as existing technology and institutions were not changed.

Why the Chinese bureaucracy in earlier centuries came to play

20. Mencius, the Chinese philosopher who helped spread the teaching of Confucius in the third century B.C., mentions that "the Minister of Agriculture taught the people to sow and reap, cultivating the five kinds of grains" (cited in Fei, 1953, p. 65n).

21. In scientific development, too, the state played a major role in China, publishing books, keeping records, financing scientific expeditions, initiating medical research, and constructing scientific equipment. Some famous inventions are attributed to bureaucrats. Chang Hêng, a mathematician and inventor who lived in the second century A.D., and is credited with the first seismograph, was president of the Imperial Chancellery. Tshai-Lun, who invented the use of mulberry tree bark in papermaking, was a eunuch in the imperial service, in charge of instruments and weapons.

such an active role in technological progress is not easily explained. Its roots are often associated with the dependence of agriculture on public works in water control that led, in Wittfogel's famous term, to a "hydraulic despotism" that needed a bureaucracy capable of managing large projects (Wittfogel, 1957, pp. 22–59). Wittfogel insisted that such projects were aimed exclusively at social and political control. It is by now widely realized, however, that water-control projects were managed largely by local authorities and landowners.[22] The central government was involved in water-control projects largely through the diffusion of technological information and the legal aspects of water rights. Still, the notion that the ruler of a society had a responsibility toward its subjects, that there was a reciprocal exchange in the relationship between the population and the authorities, was an ancient Chinese concept firmly rooted in the teachings of Mencius whose influence grew during the Sung dynasty. The Chinese state produced its own requirements of iron, ships, and large-scale construction. Its granary system system stabilized food supplies. The state monopolized trade in some goods (such as salt), and foreign trade—insofar as it existed at all—was under state supervision. The pre-1800 Chinese state, in short, intervened directly in the economy, in part in an attempt to improve the economic well-being of the people. In Europe, the state's attempts to encroach upon the private domain of production usually ended in failure, and the idea of a social contract was not fully understood until the seventeenth century. In most cases the kings, bishops, city councillors, and whoever else represented the state in Europe were little more than another consumer, buying, selling, hiring, and borrowing at prices dictated by a larger market.

Perhaps the state assumed such a central role in China because the landed gentry and intelligentsia displayed little interest in technology, leading to a vacuum that had to be filled. The role of the Chinese elite in inhibiting the advance of technology is central to a number of interpretations. Fei (1953, pp. 72–74) advanced an argument similar to the one made earlier in connection with classical civilization. If the educated and powerful classes are not interested in production and lack technical knowledge, they will not make any effort to introduce technological improvements, and stagnation will ensue. Fei's central argument was that in traditional Chinese society the intelligentsia was a class without technical knowledge, interested mostly in the wisdom of the past, literature, and art. By regarding the world through human relations, he maintained, the Chinese intelligentsia were a conservative force, because in human relations the

22. For a summary of the Wittfogel debate, see Harris (1977, ch. 13).

end is always mutual adjustment whereas technological change leads to social disruption. Fei's explanation is somewhat vague: there is no specification of the dates he has in mind when he writes of "traditional China," nor does he state whether any changes in the outlook of the intelligentsia occurred during the Ming and Qing dynasties. Surely the lack of interest in technical matters is a common enough phenomenon among all intelligentsias. Nevertheless, the central idea that technological progress needs a bridge, however narrow, between the educated class and the working class seems a logical proposition. In China, this bridge was provided by the government.

Empires are thus not necessarily antithetical to technological progress. But the Chinese example provides us with some insight into why a negative correlation between the two has been observed. First, China has, in Needham's term, always been a "one-party state" and for 2,000 years it was ruled by the "Confucian party." In the Qing (Manchu) era, the bureaucracy did not encourage intellectual or political deviants, although the violent religious intolerance of Europe was alien to the Chinese. In contrast to Europe, there were no small duchies or city-states to which bright men with new ideas could flee. Moreover, China in the Ming and Qing eras was run by a professional bureaucracy that was at least in theory selected through competitive examinations (in practice the process was often rife with corruption and nepotism). Desirable as such a meritocracy may seem to the student of European history accustomed to rulers marked mostly by greed, violence, and incompetence, the mandarinate exacted a heavy price in terms of economic progress. By attracting, at least in principle, the best and the brightest from the commercial class, the system focused the nation's intellectual resources toward bureaucratic activity, which was by its very nature conservative. Although Needham's (1969, p. 202) conclusion that "the one idea of every merchant's son was to become a scholar, to enter the imperial examination, and to rise high in the bureaucracy" is somewhat exaggerated, it does highlight a crucial difference between Europe and China.[23] In Europe, engineers, inventors, merchants, and scholars rarely belonged to the ruling class. Talented men who were not born into the right families could not, as a rule, occupy positions of power, and thus channelled their energies elsewhere.

Most important, however, is the fact that technological change that is generated in large part by public officials and a central government has the nasty weakness of depending on the government's approval. As long as the regime supports progress, progress can proceed. But the government can flip the switch off, so to speak, and private enterprise is then unlikely to step in. Innovation that is run largely by bureaucrats is thus not impossible, but it depends on their goodwill. Because most entrenched bureaucracies tend to develop a strong aversion to changing the status quo, state-run technological progress is not likely to be sustained over long periods. The Chinese miracle is indeed that it lasted so long. It ended when the state lost interest in promoting technological change.

Why the Chinese state changed its attitudes toward technological change is hard to determine. The Ming and Qing emperors were more absolute and autocratic than their predecessors. Before them, coups d'état and regicides occurred frequently, thus introducing an element of "competition" into the Chinese political market. Rigid etiquette and complete obedience and conformism became the hallmark of the Chinese government under the Ming emperors. At the same time the Chinese civil service became a major force in preserving the status quo. It learned to resist changes it did not want, and not even the most powerful emperors could implement progressive policies. The two great enlightened Manchu despots, K'ang Chi (1662–1722) and Ch'ien Lung (1736–1795), whose rules are invariably described as peaceful and prosperous, were interested in pacification, order, and administration. In their search for stability, their interests and those of the bureaucracy converged. The absolutist rule of an all-powerful monarch whose preference was for stability above all discouraged the kind of dynamism that was throbbing throughout Europe at the time. One specialist (Feuerwerker, 1984, p. 322) concluded that under Ming and Manchu rule the state "contributed little if anything toward modern economic growth."[24] This view may be somewhat exaggerated, as the imperial court was very active in bringing about the recovery of the late seventeenth century (Shang Hung-k'uei, 1981). Economic expansion did not grind to a halt in the eighteenth century. Agricultural growth occurred primarily through deforestation and clearing of the southern provinces, for

23. On the basis of official biographies, Wittfogel (1957, pp. 351–52) concludes that only a small minority of officials were commoners. But the proportion was rising: whereas in the T'ang period (618–907 A.D.) fewer than 10 percent of all officials were commoners, their proportion rises to 23 percent under the Ming dynasty, a trend that continued under the Manchus.

24. It is possible that part of the reason that the Chinese government lost its leadership role in technological change was that its resources shrank relative to the economy. The revenues of the Chinese central government declined after 1400 and amounted to only a few percentage points of national income, according to Perkins (1967, p. 487). Feuerwerker's (1984, p. 300) figures are higher, but they too imply a sharp fall from 13 percent of national income around 1080 A.D. to 4–8 percent by about 1750. Laffer-curve theories that associate economic dynamism with low taxes will have a hard time explaining this one away.

which the government provided active support. Commercial expansion was a natural consequence of the stability provided by the enlightened Qing despots. But there is little evidence for the kind of technological dynamism of Sung China or eighteenth-century Europe. By the fifteenth century, the role of the imperial government in both invention and innovation was far less remarkable than it had been in medieval times, and no other entity in China was in a position to replace the state in promoting technological progress. There were no substitutes for the state in China. In Europe, precisely because technological change was private in nature and took place in a decentralized, politically competitive setting, it could be sustained in the long run, it could make great leaps, and it could continue unabated despite serious setbacks and obstacles.

CHAPTER TEN

The Industrial Revolution: Britain and Europe

As we have seen, after 1750 the Industrial Revolution was initially concentrated primarily in Britain. Explaining Britain's headstart on its Continental neighbors has been a popular pastime among economic historians for many decades now, though a consensus has failed to emerge. In some global sense, the question may seem relatively unimportant compared to the much larger question of why such a deep gap opened between Europe and most of the rest of the world in the same period. Nevertheless, the variance within the West, the "successful" part of the world, remains puzzling as well. The difficulty is that during the British Industrial Revolution there were changes in many aspects of the economy that were not technological in nature, and it is impossible to disentangle demographic change, urbanization, enclosures, wars, social and commercial policy, and so on from technological changes and then compare the outcome with what happened on the Continent. In what follows, I shall confine myself to the questions of why Britain managed, for about a century, to generate and diffuse superior production techniques at a faster rate than the Continent, and serve as a model that all European nations wished to emulate and how and why it eventually lost its leadership in technology.

Technological success depended on both the presence of positive elements and on the absence of negative ones. Among the positive factors, the generation of technological ideas and the ability to implement them seem a natural enough point from which to start. The generation of ideas, as we have seen, was often an international effort. The British, to be sure, were prominent in providing technologically revolutionary ideas: there can hardly be any question that most of the truly crucial inventions in the period were made by