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TECHNOLOGY AND VALUES IN TRADITIONAL CHINA AND THE WEST: I

KENNETH R. STUNKEL

This essay is organized around two points. First, it was the failure of traditional China to institutionalize available technology and a spirit of technological innovation, especially in the eighteenth and nineteenth centuries, that influenced most profoundly the sad results of conflict with the West after 1840. The much discussed non-development of science in the Galilean-Newtonian mode is mostly irrelevant to an understanding of Chinese reluctance to mobilize a rich technological tradition for an effective defense capable of preserving both political and economic autonomy against encroachments of the West.

Second, China’s lack of interest in specific values associated with steady technological progress and control of nature was not a case of stagnation or inertia, but rather a coherent and stubborn expression in historical time of priorities radically different from those which came to prevail in western Europe. Those priorities were lodged in stable, persistent social institutions and a sophisticated structure of ideas and values about nature, society, and human nature.1

*Technology and the Chinese “Puzzle”*

Understanding China’s failure to enter the modern world self-consciously and advantageously, compared to Japanese success when faced with the same western challenge, has been linked to the non-development of modern science in the Chinese empire. This issue has generated wide debate and is variously posed as “Needham’s Puzzle,” the “Scientific Revolution problem,” and the “Great Question.” How, that is, does one explain the absence of modern science—meaning the Galilean/Newtonian notions of method, causation, and explanation crystallized in the seventeenth century—in a civilization so abundantly endowed with
promising scientific and technological achievements?² The latter facts have been documented by Joseph Needham and his collaborators in the monumental and still uncompleted *Science and Civilization in China.*³

My contention is that the non-development of modern science was relatively unimportant for China's nineteenth century crisis. More fundamental was the failure of the Empire to achieve sustained institutionalization of its indigenous technology, either in a modified market mode or a bureaucratic command mode, so as to promote deliberately a spirit of innovation and improvement, especially in technologies bearing on warfare and industrialization such as iron production, time keeping, nautical science, weapons manufacture (especially artillery), explosives production, and the like. This point invites a useful distinction between scientific and technological rationality. The function of science is to discover what is already present in nature—laws, processes, and regularities not of human origin. Technology is a human activity which creates or designs something not in nature for purposes of utility, control, and convenience—a seaworthy ship, a bridge, a crossbow, a water wheel, a blast furnace for iron smelting, all of which depend on laws of nature, but not necessarily on knowledge of those laws.⁴

Theoretical science is not required to produce usable and sophisticated technology, and it is not helpful to lump them together or to say that technology is really applied science, which merely fudges their distinctiveness as human enterprises.⁵ Nor can it be assumed out of hand that in Europe there was significant linkage between the two in the seventeenth century or perhaps even earlier. Until the nineteenth century it is more likely that technology developed in response to social, economic and military pressures, especially the latter, than to scientific ideas. Until quite recently progress in technology does not seem to have required parallel progress in science as a precondition, although a case to the contrary has been made that early inventions of the European industrial revolution were possible only because of widespread scientific literacy and a mechanical way of thinking.⁶ If the latter view is correct, however, then one is hard pressed to explain Chinese accomplishments in mechanical engineering in a culture whose governing ideas were non-mechanistic. The Chinese were not unaccomplished in mathematics, notably
algebra, but mathematical study was pretty much a handmaiden of the calendar. The belief system of the ruling elite viewed the universe as a self-sustaining, self-operating organic system. Since there was no Chinese law-giving creator, there were few perceived regularities in nature inviting specifically mathematical description, and therefore no incentive to contrive a mechanical frame of reference. Yet the Chinese still demonstrated a gift for developing and using ingenious machines.  

China had an impressive body of technology and various identifiable sciences, but there was no overarching conception of science as a systematically experimental, quantitative approach to natural phenomena whose findings were accumulated and criticized over time. There were no philosophers like Aristotle, Descartes, or Francis Bacon working on a common frame of reference that would embrace all scientific inquiry. There were cumulative technical traditions in which the work of predecessors was studied and valued, but these were filial lineages (jia) in which texts were invested with scriptural charisma, not schools like those of ancient Greece in which texts were dealt with critically. These Chinese traditions of medicine, alchemy, or mathematical harmonics were not traditions in the sense that Hugh Kearney uses the term to identify at least three coherent, competing approaches to nature in fifteenth and sixteenth century Europe, “each with their own assumptions about God, Nature, and scientific method”—an organic tradition whose authorities were Aristotle and Ptolemy, a magical tradition championed by people like Bruno and Paracelsus, and a mechanist tradition that finally triumphed through the work of Galileo and Newton.  

Despite the existence of well organized scientific traditions in Europe, the secret of western power at the time of the opium war was not a scientifically driven technology, but a social order friendly to technological improvement and change, which had been institutionalized consciously within educational, commercial, and political frameworks. Central to the success of western technology was a cluster of values—time discipline, efficiency, the truth value of practical results, and deliberate innovation—linked to a conception of human nature that acknowledged active control of physical nature, and rationalized the accumulation and exercise of economic, military, and political power. Theoretical science was of marginal importance. This was also true of China.
Technology did not rely on science, which was the possession of an educated class and transmitted in books. Technology was, on the whole, in the hands of skilled artisans who transmitted their knowledge directly to relatives and apprentices. The secret of China's apparent ineptitude when finally confronted by western mechanized power, despite a long historical record of invention, was that a stable cultural tradition and a tightly organized social order resisted the potentially disruptive effects of open ended technological innovation and did not consistently exploit achievements of the past. Thus Needham's Puzzle can be rephrased. Why did a civilization equipped with so much technological aptitude fail to institutionalize technological innovation and rationality when it became politically and strategically imperative to do so? The "scientific revolution problem" defers to the "technological revolution problem."

Consider for a moment what China had done. Not only were the inventions spectacular—paper, printing, the magnetic compass, the stern post rudder, the seismograph, trace and collar harnesses, the segmental arch bridge, deep drilling, the mouldboard and plough share, the earliest vaccination, the first cybernetic machine, fire arms, cast iron, and a host of engineering devices such as the chain drive—a number of them passed to the West through various intermediaries. Needham argues that... most of the steam engine's anatomy had already come to the West by the +15th century ..., namely the double acting principle of piston and cylinder, and connecting- and piston-rod assemblies for the interconversion of rectilinear and rotary motion. In the case of gunpowder (hua yao), which was invented in the tenth century A.D., military applications were made with explosive fire arrows, grenades, and barrel guns between 969 and 1275 A.D. Chinese armories mass produced cannon.

It seems clear that for half a millennium from 1000 to 1500 China was preeminent in the world for wealth, military power, and technological innovation. In the early Sung Dynasty an extensive coke-fired iron industry developed in the provinces of Honan and Hopei, with iron production rising from 32,500 tons in 998 to 125,000 tons in 1078. These were semi-capitalistic enterprises employing hundreds of workers, tied into extensive transportation networks, involving large-scale development of metal and coal resources, applying advanced technology (e.g., blast
furnaces fed by a continuous flow of air), requiring complex financial transactions, and used to provide metal for coins, construction, tools, weapons, and body armor. While the extensive Sung navy was designed to operate mainly on rivers and canals, the Ming navy in the early fifteenth century was an open-ocean force capable of overwhelming several European states combined with its 1,350 combat ships. Kublai Khan sent more than 4,000 ships against Japan in 1281. In the first half of the fifteenth century, wide-ranging tributary fleets of the Ming admiral Cheng Ho were capable of asserting a military and commercial empire as far as the eastern coast of Africa. His largest vessel displaced some 1,500 tons (Vasco da Gama’s flagship displaced 300 tons), and was equal to navigation across the Pacific. Chinese military technology and industrial accomplishments anticipated those of Europe by several hundred years, and the scale was sometimes awesome. When these feats were repeated in the West they established Europen supremacy in the world. Why did the early initiatives falter and slump into desuetude? With such a reservoir of precedents, why were the Chinese unable to revive, mobilize, and augment them after 1840?

Wen Yuan Qian argues that China failed to develop modern science because of stagnation. Much of his argument could be applied to the absence of sustained technological innovation as well. The trouble with this stagnation hypothesis, which has been shared by many, is that Qian blames traditional Chinese civilization for not self-consciously preparing itself to meet challenges of the modern world, a palpably unhistorical line of argument. In the context of China’s present comparative weakness as a modernizing nation, he excoriates traditional Confucian rationalizations of despotism and agrarianism, its reliance on moral interpretations of the past to guide the present, and its domination of an educational and civil service system shaped by literary studies. Like Hu Shih (1891-1962) before him, who fled Chinese tradition for democracy, evolution, and John Dewey, the first Chinese intellectual to make such a clean break, he repudiates wholly the influence of “The Antique Shop of Confucius and Sons.” On the other hand, those institutions and ideas which account for China’s longevity as a civilization can be viewed historically as signs of strength. A legitimate reading of Chinese civilization is to stress its persistent stability for some two thousand years.
following the First Empire of 221 B.C., even allowing for violent dynastic transitions and a long period of disunity between the Han and Sui Dynasties. Despite China’s troubles in the nineteenth and twentieth centuries, it is not misguided to be impressed by such uncommon staying power and continuity, and to see it as an exemplary historical achievement.

Let us suppose that a K’ang Yu-wei (1858-1927) and the educational, administrative, and economic reforms of the 100 days of 1898, including a constitutional monarchy, encouragement of invention, permission for Manchus to become traders, the establishment of bureaus to promote agriculture, industry and commerce, the right of all officials and subjects to direct suggestions to the throne—all supported by the Tao-kuang Emperor—had been the response in 1841 to the crisis of the Opium War. Would it have made a difference? I think not. The Confucian mandarinate was not inclined to reform China on some quasi-radical model any more than the “enlightened despot” Joseph II was able to reform the Austrian Empire through decree at the end of the eighteenth century. Sung proto-industrialization was first promoted and then discouraged by the bureaucracy when it was perceived as a threat to social balance. The imbalance came from placing too much wealth in the hands of merchants and too much power in the hands of generals, which undermined the agricultural sector on the one hand, and the ruling elite on the other. Europeans relished a symbiotic relationship between armaments and money making after the fifteen century. For the Chinese literati it was less desirable to accumulate wealth than to keep merchants in their place, and better to risk military defeat (in Sung times passive defense was actually chosen over active defense, which led to the loss of north China) than to risk an unmanageable army always hungry for the latest technology.

The readiness for change in all social classes and institutions requisite to comprehensive reform of familiar ways was absent. There was no conspiracy by the governing elite to squash capitalism or to hamstring technology. For Confucian literati, the cultural and social air they breathed, and the restraints it imposed, seemed as natural and fundamentally real as the water in which a fish swims. So it seemed also for virtually everyone else in Chinese society. Chinese talent was equal to industrialization, technological innovation, and sophisticated commercial organi-
zation well before Europeans embarked on those paths, but values of social harmony and "change within tradition" asserted themselves over the impulse to seek power through wealth and technology. After the great upsurge of innovation and commercial experimentation between the Sung and early Ming periods, Chinese initiatives retreated into the cautious stability of the Ming and Ch'ing dynasties, which together stretched from 1368 to 1911 A.D., well over 500 years, the very time span in which the West began to experience its scientific and technological progress, accompanied by unprecedented social, religious, economic, and political upheaval. The brilliance was still there, but not to serve ends of technological control and innovation.

Consider an instructive example in civil engineering—bridge building, which has implications both for commerce and defense. In nineteenth century Europe traditional building materials of wood and stone were challenged and, in some special cases, displaced by the use of industrialized iron. The new material led to the creation of novel engineering forms. Thus Thomas Telford, functioning as a public servant, was throwing cast-iron arches over rivers in the first decades of the century, taking full advantage of the new technology to transform an important category of public works. Motivated to combine strength and beauty, he modulated quickly from arches to cables and from cast-iron to wrought-iron. The 150 foot-span Craigellachie Bridge over the Spey River in Scotland (1814), an iron-arched structure, is still standing. Telford's Menai Straits suspension bridge in Wales (1826), a spectacular 580-foot-span, wrought-iron structure, the longest in the world for its time, also still with us, became in inspiration for similar structures into the twentieth century and was a symbol of pre-Victorian industrial power and innovative genius.

These structures erupted on the world very suddenly through one man whose pragmatic genius was recognized and given scope by the social order. Telford and others institutionalized the use of industrialized iron as a universal material of structural engineering. His designs had a pervasive impact on an engineering profession and public consciousness. Telford's work came from the insight that cast-iron could carry many times the load of wood or stone, and hence is superior in strength, durability, and economy. His structures were possible because of a social order that valued
such public works at low cost. As an author of treatises and president of the first civil engineering society he disseminated his views to a receptive public, and “industrialized iron came to define the course of technology and society as a whole.”²⁰ By the end of the century Gustav Eiffel gave French nationalism and industrial aspirations a shot in the arm with the world’s tallest tower, erected from prefabricated iron parts, the forebears of that famous work being a whole series of railroad viaducts Eiffel built in the Massif Centrale by government commission. An iron tower became a symbol of national power and technological greatness.²¹

The Chinese built segmental arched and suspension bridges very early and in many locations.²² The materials were bamboo, wood, stone, hemp, and iron suspension chains. The arched bridges were chiefly masonry structures. In time the suspension bridges were using wrought-iron chains for support anchored in masonry abutments. Taken as individual physical artifacts these structures could be impressive. Thus the An-Lan suspension bridge at Kuanhsien, fabricated of wood, hemp, and bamboo, has eight spans (the longest is 200 feet) totaling 1050 feet.²³ The Chin-Lung iron-chain bridge crossing the Yangtze in Yunnan Province has a single span of 328 feet carried by 18 chains.²⁴ The Wan-Nien Bridge at Nanching spans 1,803 feet over the Ju Shui River with no less than 24 arches.²⁵ These structures are admirable and China’s priority in conceiving and executing them must be acknowledged. On the other hand, bridge building was a local initiative in China which had only slight potential for absorbing technical improvements. Once certain forms were in place they were sufficient to meet traditional needs, which was mainly foot traffic and light loads. Moreover, “everything seems to have been done by traditional eotechnic methods showing little or no trace of modern influence.”²⁶ The Wan-Nien Bridge illustrates very well the role of traditional technics in China. It was completed in 1647 on the initiative of a provincial official. It was damaged by floods in 1887 and repairs were undertaken by one Hsieh Kan-tang, who wrote a rare book about the event. The entire job was managed by Hsieh and his associates without pay, subscriptions provided funds for the work and materials, and many workers joined in for the sake of Buddhist piety. The imperial government provided no help at all. There was no program for reasses-
sing engineering options or developing new technology in the Ministry of Public Works. The Wan Nien initiative was an ad hoc operation with little potential for impact beyond the local area, Hsieh's treatise on the work notwithstanding. It was technology from beginning to end in the service of stability, order, and tradition, not deliberate innovation. It never occurred to Hsieh that he might exploit China's experience with industrialized iron and reduce future flood damage by experimenting with iron clamps between the masonry arches of the Wan Nien Bridge.

**Homeostatic versus Dynamic Change**

Qian's hypothesis of inertia and stagnation is historically less satisfying and helpful than Needham's idea of homeostasis, that is, the tendency of Chinese civilization in times of trouble and imbalance to seek equilibrium rather than to develop new social, political, and economic forms, the most spectacular instance being the three tumultuous centuries of disunity following the collapse of the Han Dynasty in the second century A.D. Following a series of succession states and the domestication of Buddhism to Chinese conditions, the empire was reestablished in the sixth century under Confucian auspices, an extraordinary and highly improbable feat, perhaps as improbable as the development of modern science in Europe. In contrast, the disintegration of western Roman civilization about the same time led to the emergence of a new civilization in medieval Europe. Needham is right to point out that "the built-in instability of European society must . . . be contrasted with the homeostatic equilibrium of China. . . ." This tendency to equilibrium was served by mutually reinforcing social, economic, and intellectual patterns organized on a principle of interactive relatedness. The outcome was an organic model of humanity, society, and nature within which the assertive ideals were adjustment and harmonization rather than change and conflict. Technological innovation, like all other change, responded to "the Chinese fondness for solutions which permit lesser change to occur within a greater permanency." This remained true virtually to the end of the dynastic period, despite sharp criticism of traditional correlative thinking by Ch'ing scholars like Wang Fu-chih (1619-1692) and others.

Western Europe was always off balance because of its geo-
graphical propinquity with Western Asia and Africa, and a diversified, often contradictory historical legacy—Greco-Roman secularism, rationalism, and humanism, Christian otherworldliness, faith, and God centeredness, rival kingdoms, republics, and principalities, confused dynastic claims, and conflicting legal jurisdictions. Most important was European curiosity after the Middle Ages about unknown lands and a marked receptivity to outside influences. For example, the transmission of texts by Aristotle and Ptolemy to the University of Paris from Toledo in the 12th century revolutionized Christian thought and provided a stimulus to scientific revolution in the sixteenth century, and Europe's era of aggressive geographical exploration and discovery in the Renaissance promoted irreversible economic, social and technological change. Europeans seemed to thrive on conflict and uncertainty. They came to rely on innovation and change as a source of power, security, and leverage in an environment of competitive political and military aspirations. The restless inventive temperament and individualism of Leonardo da Vinci was markedly un-Chinese and recognizably European.

While differences between the two civilizations must explain in the end historical paths they actually took, there were many striking similarities prior to the nineteenth century, all of which bear in some way on technological development, thus intensifying the puzzle of China's disastrous clash with the West. Both civilizations relied heavily on an agricultural base. Both had political and social orders resistant to change—China its ruling class of "scholar-gentry" and Europe its Old Regime. Both had considerable wealth generated by commercial and financial activities of a merchant class, potential capital for investment in productive and innovative undertakings. Both had thriving town life, a Sung Dynasty phenomenon with the Chinese, a Renaissance development with Europeans. Both mounted large-scale productive enterprises involving large numbers of workers and the leadership of merchants, nothing less than incipient capitalism. Both devised advanced methods for commercial and financial transactions—China's "flying money," proto-banks, and promissory notes, Europe's double entry bookkeeping, joint stock companies, and international trade. Both had military establishments linked to proto-capitalist methods of production. Both had a correlative way of thinking about nature and society that featured organic
correspondences. Both had ingenious technological aptitude. Both had developed what Braudel calls "the three great technological 'revolutions' between the fifteenth and eighteenth centuries..."—artillery, printing, and ocean navigation.32

But it was differences nested in these similarities that collectively diverted China from progressive technological development. Conditions in Europe favored an outlook that was quantitative, controlling, innovative, and entrepreneurial, which undermined feudal institutions by reorganizing and redirecting human energies to produce wealth for the sake of military and political power. Historical experiences and conditions in the West favored technological innovation in part because change, measurement, mechanical arts, power, and the calculating mind acquired dignity. Human nature embodied a rational, manipulative mind oriented outward to an intelligible natural order created by God. The metaphor of God as creative Artisan pointed to similar powers in man. These values were supported and strengthened by specific institutional arrangements and incentives in the monarchies and republics of western Europe.

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NOTES

1. The Wade-Giles system of transliteration is used in this essay. Pinyin appears in some quotations and in the names of recent Chinese authors.

2. On the "puzzle," see Wen-yuan Qian, The Great Inertia: Scientific Stagnation in Traditional China (London: Croom Helm, 1985), pp. 92-94, and Nathan Sivin, "Why the Scientific Revolution Did Not Take Place in China—or Didn't It?", in Li Guohao, et al., Explorations in the History of Science and Technology in China (Shanghai: Shanghai Chinese Classics Publishing House, 1982), p. 89. Needham alludes to the puzzle, or paradox, throughout his writings. Scholarship, he says, is concerned not only with what the Chinese did, "but why they did not succeed, as Europe's civilization did, in giving rise to modern science and technology. Why did their science and technology always remain primarily empirical? Why was there no indigenous industrial revolution in China? That, I believe, is one of the greatest problems of all comparative social history..." Clerks and Craftsmen in China and the West (Cambridge: Cambridge University Press, 1970), p. 72. In another place he says the question to be answered is "the failure of two great Asian civilizations, China and India, to develop spontaneously modern science and technology," The Grand Titation (Toronto: University of Toronto Press, 1969), p. 177. This is one of three big themes that form Needham's conceptual frame of
reference like a triple fugue. The second is: “why had China been more successful than Europe in gaining scientific knowledge and applying it for human benefit for fourteen previous centuries?” Joseph Needham, 


3. Needham and his collaborators have produced six volumes to date, some divided into “parts” because of their copiousness, which yields an actual total of 15 volumes. Science and Civilization in China, 6 vols. (Cambridge: Cambridge University Press, 1959-). This key work is cited hereafter as SCC. There are critical reviews of the project by Lynn White, Jr. and Jonathan Spence in Isis, 75:276 (March 1984): 171-189. There is an abridgement of SCC in the making, which one might expect to ease somewhat the task of seeing the forest through the trees, much like D. C. Somervell’s useful abridgement of Toynbee’s A Study of History. Unfortunately Ronan’s compressions do not always preserve the integrity of Needham’s arguments and insights, and is no substitute for direct reference to SCC. So far there are two volumes in the abridgement covering the first three volumes and a section of volume IV:1 of SCC. See Colin Ronan, The Shorter Science and Civilization in China (Cambridge: Cambridge University Press, 1978-).

4. Frederick Kilgour notes an “almost total absence of technological innovation in colonial America.” But in the half century after independence, “Americans produced a baker’s dozen of major technological innovations,” not because of science, but because of a new competitiveness, high labor costs, the stimulus of English industrialization, and legislation such as the Patent Act of 1790. “Technological Innovation in the United States,” Journal of World History, 8:4 (1965), p. 745. In Europe there was “a truly scientific technology” in the development of instruments used by science. John Burke (ed.), The Uses of Science in the Age of Newton (Berkeley: University of California Press, 1983), pp. 106-107. Theoretical astronomy did serve a practical need; thus Giovanni Cassini’s late seventeenth century almanac gave eclipse times of Jupiter’s moons that permitted a determination of longitude on land, and there was clearly some relevance of astronomical knowledge to John Harrison’s chronometer, the instrument which solved the problem of finding longitude at sea. On the other hand, Harrison really licked the problem by reducing irregularity in a mechanical time keeper caused by temperature changes and friction in the escapement, not by applying theoretical astronomy. Ibid., pp. 150, 155-161. There was also some linkage between practical needs and the kinds of problems scientists chose to pursue, as in the case of seventeenth century gunnery, but the outcomes were technically insignificant. Ibid., p. 136. Carlo Cipolla holds that “… the resources of craftsmanship were strengthened by the systematic application of scientific principles. . . .” which is not the same as saying the former depended
on the latter. *Clocks and Culture, 1300-1700* (New York: W. W. Norton, 1977), p. 36. None of this justifies claims that technology was the offspring of science in early modern Europe.

5. A. Wolf rescues technology from being “applied science” and states my position succinctly: “the invention of things and processes, on the one hand, and the discovery of their nature and laws on the other hand, are activities which may be pursued more or less independently, and have been so pursued in the earlier history of civilization, though, with the growth of knowledge, they tend to become closely interlinked.” A History, Science, Technology, and Philosophy in the 16th & 17th Centuries (New York: Macmillan Co., 1935), pp. 450-451. For example, the innovative Scottish builder of industrialized iron bridges in the early nineteenth century, Thomas Telford, made no use of Galileo or Newton, “had little use for the science of his day, was untrained in mathematical formulations, and made few if any calculations for his designs.” *The Tower and the Bridge: The New Art of Structural Engineering* (Princeton, N.J.: Princeton University Press, 1983), pp. 41-42. Robert Merton, in a new introduction to his 1938 classic, *Science, Technology and Society in Seventeenth Century England* (New Jersey: Humanities Press, 1978), says about the section on military and economic effects on science that “it distinguishes throughout...between science and technology, an essential distinction that...was not uniformly made back in the days when the monograph was written and one that is often blurred even today.” Ibid., p. xiii. For a cautious dissenting point of view, see Edwin Layton, Jr., “Technology and Science, or ‘Vive la petite difference.’” *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 2 (1976), pp. 173 ff.

succeeded only in “validating and explaining, not in improving techniques developed earlier and without science’s aid.” “History and the History of Science,” *Daedalus* (Spring 1971), pp. 284-285. One finds everywhere in Needham’s writings the assumption that science and technology are inseparable. For example: “When we say that modern technology did not develop, we mean that the science (my italics) of the Chinese always remained empirical, and its theories were confined to those of ‘primitive’ type, such as the Yin Yang principles and the Five Elements.” *Clerks and Craftsmen*, p. 76. 5.

7. On the immense range of Chinese mechanical engineering developed in an “organic” cultural milieu, see SCC, IV, 2: *passim.* A. G. Keller argues that mathematical study was important to technological advances in sixteenth century Italy because of the premium on developing effective artillery. See “Mathematicians, Mechanics, and Experimental Machines,” in Maurice Costland (ed), *The Emergence of Science in Western Europe* (New York: Macmillan Press, 1975), p. 16. On the relation of mathematical thinking to Chinese civilization, the most recent work is by Jean-Claude Martzloff, *Histoire des mathematiques chinoises* (Paris: Masson, 1988). Martzloff has changed minds about the ability of Chinese mathematicians to produce rigorous proofs, especially their understanding of Euclid’s methods. But notational problems tended to hold them back, and “it is striking that throughout Chinese history the main importance of mathematics was in relation to the calendar.” SCC, III: 152.

8. For discussion of what might be meant by Chinese “science” and “scientific tradition” in current scholarship, see Nathan Sivin’s state of the art review, “Science and Medicine in Imperial China—The State of the Field,” *The Journal of Asian Studies*, 47:1 (February 1988). While Needham tends to fuse science and technology in the Chinese tradition, Sivin avoids lumping them together and distinguishes nine “self-conscious sciences” and has little to say about technology. Ibid., pp. 43-44, and 46-47 on Needham’s assumptions. While explorations in these sciences—such as mathematics, medicine, alchemy, geomancy—have produced a substantial recent literature, Needham’s work in SCC remains indispensable and unique for detailed accounts of Chinese technology.

9. See Hugh Kearney, *Science and Change, 1500-1700* (New York: McGraw Hill, 1971), p. 48 on European scientific “traditions.” One might argue that the naturalistic systems of Yin-Yang and the Five Elements, particularly the latter, were a “tradition.” But rather than providing a basis for systematic, testable observation of phenomena, as did the Aristotelian idea of qualitative change, the neo-Platonic concept of microcosm-macrocosm, or the Cartesian notion of mechanical laws, they were used to formulate a complicated system of symbolic correlations whose divinational and quasi philosophical applications were more sought after than critical explorations of nature. The correlative approach to cataloguing and explaining phenomena was not above sharp criticism (e.g., the Han skeptic Wang Chung), but it did not lead to fundamental conceptual change. Needham notes that “the more elabo-
rate and fanciful the symbolic correlations became, the further away from observation of Nature the whole system tended. By the time of the Sung (+ 11th century) it was probably having a definitely deleterious effect on the great scientific movement which then developed.” SCC, II: 261-266. On specifically Chinese notions of science and tradition, see Sivin, “Science and Medicine in Imperial China,” pp. 42-43. On the absence of common ground for the sciences in China, see Nathan Sivin’s account of the Sung Dynasty polymath Shen Kua in “Why the Scientific Revolution Did Not Take Place in China—Or Didn’t It?”, pp. 90-93.

10. Sivin, ibid., p. 90.

11. For a useful tally of the most important Chinese inventions and the ones that probably reached the West, see Charles Singer, et al., A History of Technology, 5 vols. (Oxford: Clarendon Press, 1954-1958): II, 770-771. See also Joseph Needham, The Grand Titration, pp. 34, 52, 188, 213. 14: Needham, Clerks and Craftsmen, p. 62. He believes a possible mechanism of transmission was movement to Italy through the slave trade, from the Middle Ages into the fifteenth century, of numerous Tartars (Mongols) who became servants. Ibid., p. 61.


14. Qian’s key assumption is that “software decides,” meaning the social structure, language, and bureaucracy of traditional China were decisive, and not “hardware,” that is, the availability of tools and machines. The non-development of science, and by extension, technology, was due to “the non-development of modern economy, modern politics, and modern culture.” The Great Inertia, p. 24. What Needham
calls a tendency of Chinese civilization to move from disturbance or disruption to "equilibrium," the principle of homeostasis, Qian calls "inertia." Ibid., pp. 94-95. Compare H. G. Creel's view that early imperial China had many of the features associated with twentieth-century superstates—necessarily strong centralization and sophisticated bureaucratic organization. Ray Huang, *Taxation and Governmental Finance in Sixteenth-Century Ming China* (Cambridge: Cambridge University Press, 1974), p. 309. Huang lays his finger on a feature of the entire late imperial period when he points out that "the Ming represented an attempt to impose an extremely ambitious centralized system on an enormous empire before its level of technology had made such a degree of centralization practical." Needed were "transportation, communication, other service facilities, the principles of money and banking, techniques of accounting and data processing, and even the mental attitude of the officials." Ibid., p. 313.


17. McNeill notes generously: "However costly their policies may have been in the long run, westerners in the twentieth century can surely sympathize with the problem Confucian officials faced in trying to balance one disturbing element—professionalized violence—against another equally disturbing element—professionalized pursuit of profit. Neither conforming to traditional propriety. . . . Uninhibited linkage between military and commercial enterprise, such as was to take place in fourteenth- to nineteenth-century Europe, would have seemed disastrous to Chinese officials." *The Pursuit of Power*, p. 40. With regard to bureaucratic efforts to marginalize military influence through financial controls, the drive towards capitalism was thereby dampened. In the West professional armies were at the center of public finance. Indeed, "armies were of overwhelming importance for the development of capitalism. . . . supplied the first great markets for mass consumption in modern times. . . . and were the only large-scale purchasers of iron products in the middle of the eighteenth century." Walter Dorn, *Competition for Empire, 1740-1763* (New York: Harper & Row, 1940), p. 15.

18. J. K. Fairbank and E. Reischauer see the stability of traditional Chinese civilization as an obvious reason for failure to modernize. On the other hand, "the comparison with the revolutionary and expanding society of the West should not be permitted to stigmatize the Ming and
Ch'ing periods as retrogressive, or to overshadow their real achievements, for the Ming and Ch'ing saw many important developments in Chinese civilization." East Asia: The Great Tradition (Boston: Houghton Mifflin Co., 1958 and 1960), p. 291.


20. Ibid., p. 29.


22. For a glimpse at bridge building of various types in traditional China, see the fold-out map in SCC, IV, 3, between pp. 208-209. See the Table on segmental arch bridges in China and the West, Ibid. 181. Information on 24 iron-chain suspension bridges is detailed in another table, Ibid., 194-195. The longest span listed for an iron-chain bridge is some 430 feet. The shortest is 50 feet.

23. Ibid., Plate CCCLIV, Figure 848.

24. Ibid., Plate CCCLVII, Figure 854.

25. For an example of such an arched bridge, see Ibid., Plate CCCL, Figure 841.

26. Ibid. 173.

27. Ibid.

28. "The world that the Sui leaders aspired to unite once more into a single political and cultural order was immensely complex, comparable ... to that of Charlemagne's Europe, with the orthodox and legitimist pretensions of the East Roman Empire thrown in." Arthur Wright, The Sui Dynasty (New York: Alfred A. Knopf, 1978), p. 21. On the reemergence of Confucianism, this time rivaled by the material and spiritual power of Buddhism, see Ibid., pp. 120-123.


