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Structural Factors in the Origins of Modern Science: A Comparison of China and Europe

Introduction

In the late 1930s Joseph Needham first turned to the question of why modern science developed in Europe but not in China and began his life's-work on science and technology in China. But increasingly he devoted his efforts to chronicling the achievements of science and technology in pre-modern China, and largely abandoned the original question.[1] This is fortunate for the history of science, but unfortunate for those still interested in that great question in the sociology of science. Some scholars have maintained that while we may explore the causes of the rise of science in Europe, we cannot ask why such a development did *not* occur in China or India (Graham).[2] But others continue to pursue the answer to Needham's question, especially through comparative research (e.g., Karp and Restivo; Dorn; Huff). Their explanations can be classified according to the type of factor which each theorist believes is primary. Proposed causes or conditions for the rise of science in Europe, and for the lack of such a development in China, can be grouped into "culturalist" and "structuralist" explanations.

The most recent attempt to provide culturalist explanations for the growth or inhibition of science in various societies is Toby Huff's 1993 book, *The Rise of Early Modern Science: Islam, China, and the West*. The most recent major structuralist analysis, attempting to explain the fate of science in terms of ecological conditions and the social and political structures which developed under various ecological conditions, is Harold Dorn's *The Geography of Science*,

1 On some of the ideological factors which may have influenced Needham's approach to the history of science, see Dorn.

2 Graham argued that the two questions — why something did occur somewhere and why it did not occur at another location — are not equivalent. Asking why China did not develop science is like asking why, among all the countries which experienced snow, most did not invent skis. See also Qian's argumentation.

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published in 1991. We might say that Huff's culturalist approach is grounded in a type of analysis which goes back to Max Weber, while Dorn's structuralist approach is grounded in a type of analysis which goes back to Engels. Thus, the classic debates of the last century in regard to fundamental causes of social and cultural change are still very much alive in current studies of the rise of modern science.

Culturalist Theories

The culturalist explanations look for the causes of the differences between two civilizations in the realm of beliefs and values. Accordingly, Europe had beliefs and values which led eventually to science while China had beliefs and values which led in other directions and which inhibited the development of science. The most common culturalist explanation for the failure of China to develop modern science holds that Confucianism is not compatible with the scientific approach to pursuing knowledge. Etienne Balazs expressed this idea as follows: "most probably the main inhibiting cause was the intellectual climate of Confucianist orthodoxy, not at all favorable for any form of trial or experiment, for innovations of any kind, or for the free play of the mind" (22; qtd. in Karp and Restivo 138). Other culturalist explanations for the rise of modern science in Europe have referred to the effects of Christian or Puritan theology, the legacy of Roman law, etc. (see Merton; Huff 1993).

One problem with culturalist explanations is that most contemporary social scientists do not view culture as a static set of ideas and rules somehow imposing itself on society. Culture is comprised of a multitude of images and ideas which are used selectively and often creatively to suit the needs of various groups. When it appears to be advantageous, a group may reinterpret elements of the received culture to support their plans, or adopt new ideas from local innovators or from other groups, provided they have the resources and the freedom to do so. If scholars in China had wanted to do science, philosophy alone would not have been a serious impediment. Indeed, there were probably fewer ideological impediments to science in Confucian China than in Christian Europe. Huff began with an explicit commitment to culturalist explanations: "the riddle of the success of modern science in the West — and its failure in non-Western civilizations — is to be solved by studying the nonscientific domains of culture, that is, law, religion, philosophy, theology, and the like" (1993, 10). Working in the Weberian tradition, he attempted to extend Weber's culturalist approach in regard to the problem of why capitalism developed only in the West to the similar problem of why modern science developed only in the West. However, between the independent variable (culture) and the dependent variable (the rise of science), Huff proposed an important intervening variable in the realm of social structure: the development of at least partially autonomous institutional settings in which inquiry can occur without serious inhibitions or constraints imposed by

the state or by religious authorities. In Europe, these institutions included relatively autonomous towns and universities with their own charters and with some degree of independence from the state.

But why did such institutions develop in Europe and not in the Islamic Middle East or in China?[3] Huff attempted a culturalist explanation. With regard to Islam and Europe, he maintained that philosophical and theological developments ultimately explain the institutional differences between the two civilizations. In Europe, the world was conceived as orderly, even mechanical, and it was believed that humans could apprehend the natural world, and regulate the social world, through reason. The origins of such beliefs, according to Huff, lie in the unique European heritage of Greek philosophy and science, Roman law, and Christian theology (1993, 314). By contrast, Islamic sacred law prevented the development of autonomous institutions which could protect and foster rationalistic inquiry because the sacred law, as interpreted by the religious authorities, applied to every phenomenon and governed every discourse. Sacred law regulated everything but could not itself be the subject of rationalistic inquiry or analysis (1993, 218-20; see also Hoodbhoy). With regard to China, Huff also attempted a culturalist explanation, based partly on an analysis of "Chinese modes of thought" (1993, 296). Following Derk Bodde, for example, he noted the weaknesses of the "correlative/analogical" mode of thought supposedly prevalent in Chinese discourse. However, it can be argued that such a mode of thought would not survive the development of vigorous scientific debate and research, and hence adducing the "mode of thought" factor merely begs the question.[4] He also noted the lack of progress which resulted from the unquestioning devotion to old writings, as illustrated by the "cut-and-paste" method of developing an argument in which any topic could be covered by simply copying passages from classical sources. Huff suggested that there was a "cultural premium ... on yielding to the priority of the classics ... and avoiding vigorous public debate" (1993, 302). There was no tradition of disputation as a method of achieving intellectual progress (1993, 303). But why should such features become dominant in Chinese culture?

It would not be difficult to relate Chinese cultural conservatism back to the character of the state-system in China and its hegemony over intellectual life — as will be argued below — although Huff does not do this explicitly. Hence, I

3 It could also be argued that Huff's analysis leaves unanswered the question of why it took the European universities 400 years to develop the basic elements of modern science, if the principal condition for such a development was relatively autonomous universities, which already existed throughout Europe by the thirteenth century. The university was evidently not a sufficient condition for the emergence of modern science (see Collins; Elman).

4 I could also argue, with Randall Collins, that the religious or pre-scientific concepts which Huff claims inhibited scientific thinking in China and in the Islamic world could equally have been construed as consistent with scientific principles if science had developed in those regions.

were some investigators who met some or even all of the methodological criteria of early modern science in their work. There is no sharp historical dividing line between "pre-modern" and "modern" science. Most historians agree, however, that the origins of modern science can be located in the sixteenth to the seventeenth centuries in Europe, where we find the first full and explicit formulations of the above epistemology and the first organized forums self-consciously devoted to critical assessment of the work of scientists (see Goodman and Russell; Garber), and which could be called scientific societies.[5]

The above list of features of modern science does not seem extraordinary, or to be obviously beyond the capacities of many societies which produced a large agricultural surplus and supported a complex division of labour. Why then did science become institutionalized only in Europe, and only from about the sixteenth century? One way to approach the problem of explaining the rise of modern science is to describe the conditions which must exist for the development and institutionalization of science. If we could determine these conditions, it should be possible to explain why science occurred in one society but not in another.

Pre-conditions for the Rise of Modern Science

I propose that for the development of modern science, the following factors may be required:

1) Surplus food supporting a complex division of labour.
2) A writing system.
3) Occupations which allow time for inquiry or investigation, especially in organizations which materially support such activities (e.g., government bureaucracy, academies). Science cannot develop or progress solely through the work of those few fortunate individuals who are independently wealthy and can carry on scientific work using their own resources.

However, while conditions 1 to 3 are necessary for the emergence of science, they are not sufficient. Here are further necessary conditions:

4) A number of sites or "nodes" in which inquiry and investigation could occur. A single site or node makes the survival of scientific work vulnerable to conditions at the site. (For example, important work might be completely lost due to war, fire, or accidents, or the site may be closed for economic or political reasons). A single site is also likely to be conservative in regard to established theories, especially those espoused by the node-leader, which may be accepted at the site because of the status and power of the node-leader rather than for scientific reasons. Hence progress in developing better theories is likely to be slow or absent if there is only one such site.

5) Unimpeded communication between nodes of inquiry. This makes progress more likely, since they can gain the benefits of each others' work, especially since they are likely to pursue different lines of investigation due to chance differences in aptitudes, interests, the influence of node-leaders, etc.

5 Dorn, however, suggests that there is no significant discontinuity between "medieval" and "modern" science in Europe, and that the apparent discontinuity in the sixteenth century is owing more to the temporary but devastating impact of the bubonic plague on scientists and universities in the fourteenth and fifteenth centuries than to any sudden or substantive difference in the developing scientific culture of the region (130-31).

Conditions 4 and 5 are probably important in stimulating the development of a scientific methodology, since one cannot convince those in other nodes of inquiry without a powerful objective method of demonstrating the validity of results or confirming the superiority of some theories over others. These conditions are probably also necessary for the survival of science over a prolonged period, as well as for sustained progress over a number of generations. Further necessary conditions are:

6) Freedom to pursue inquiries without fear of repression for non-scientific reasons (e.g., religious or political ideologies). Investigations are evaluated only in relation to the goal of knowledge, and by knowledge-related criteria (methodology, logic, etc.).
7) An education system which liberally preserves and passes on new work deemed valuable, so that subsequent generations of inquirers do not have to rediscover everything.

If there is repression of scientific inquiry for political or religious reasons, science will be inhibited, in proportion to the degree of repression. The society must be capable of tolerating a critical approach toward received theory. The society's educational system must also be capable of assimilating advances in knowledge produced somewhere within the society, otherwise there is likely to be little progress as each generation is socialized anew in the old received theory. Of course, it is possible that an otherwise repressive society allows critical inquiry in certain secluded contexts, and that advances in knowledge are assimilated and passed on in exclusive settings while the educational system as a whole remains highly traditional and conservative. Science is likely to be inhibited in proportion to the extent to which it is confined to such reclusive contexts. A society which is un-repressive, and which readily absorbs new knowledge into its educational system, provides much better conditions for the emergence of science.

However, conditions 1 to 7 could exist without causing the rise of modern science, if there is no particular reason to pursue inquiries into natural phenomena. Intellectuals could use the freedom and institutional support provided in conditions 1 to 7 to engage in activities much less tedious than

between 1450 and 1650 were university educated and about half of them held a career position in a university (Gascoigne 209). The medieval university curriculum commonly included the study of arithmetic, geometry, and astronomy (the topics, along with music, of the so-called undergraduate *quadrivium*), and thus probably included more mathematics and science than most non-science students receive in the curriculum of the modern university (see Huff 1993). The university provided a setting in which scholars and students engaged in rationalistic inquiries and analysis devoted much of their time to writings about the natural world. While scholasticism predominated for centuries, universities were capable of developing and incorporating into the curriculum writings critical of Aristotle or writings which contained major challenges to the old world-view such as those by Galileo. The work of the sixteenth and seventeenth century scientists was grounded in and stimulated by the work of earlier generations of scientists, such as in the universities of northern Italy (Randall 52).[9] Some professors in sixteenth century universities were also increasingly interested in the technical and empirical problems produced by the development of the capitalist economy, of maritime navigation for trade and military expeditions, of shipbuilding and mining, and of artillery and ballistics. For example, Gresham College in London, founded near the end of the sixteenth century and arguably the precursor of the Royal Society, provided a setting in which such professors, recruited from the universities of Oxford and Cambridge, worked on such problems (see Johnson).

Communication between these nodes of inquiry was facilitated at first by their use of Latin as the common academic language for all discourses, whether about theology, philosophy, or astronomy. The fact that Latin was also the language of the Church contributed to its survival as the literary language of Europe long after the political reality of the Roman Empire and its successors had disappeared. However, the communication among scholars in Europe depended also on the relative ease of travel between the major towns and cities of Europe, and the frequency with which merchants, traders, and students engaged in such travels. The use of the printing press in Europe from the fifteenth century allowed scholarly works to be much more quickly and widely dispersed throughout Europe, but it could be argued that the printing press was merely a response to the demand for such an invention from the rapidly increasing number of eager consumers of scholarly publications. Thus, in Europe from the late Middle Ages we find a rapidly increasing number of nodes

9 For example, on the University of Padua, at which Copernicus studied, Randall writes: "the liberty of teaching and speculation guaranteed by Venice, the leading Italian anti-papal and anti-clerical state, after its acquisition of Padua in 1405, attracted the best minds from all over Italy.... Padua remained to the days of Galileo the leading scientific school of Europe, the stronghold of the Aristotelian qualitative physics, and the trainer even of those who were to break with it" (58).

of inquiry, and a fairly rapid and effective system of communication between these nodes. By the time of Galileo, reports of an important scientific discovery in one part of Europe could be read and debated in most of the major towns and cities in Europe within weeks.

Institutions devoted to study and teaching of law and religious doctrine occurred in Islamic areas even before they developed in Europe, but these institutions (the *madrassas*) were too seriously inhibited by their focus on the work of a particular master in each case, and by pressure from religious and political authorities, to develop into centers of rationalistic or scientific inquiries (Huff 1993). Some scholars were patronized by Muslim rulers, but their fortunes could change drastically with the advent of a new ruler.[10] Reliance on such patrons by scholars in Islamic states was therefore a "dangerous structural weakness for Muslim science" (Hoodbhoy 93). In China, the state prevented the development of autonomous institutions, including those devoted to inquiry such as the universities in the West. The so-called Imperial "University" in Beijing, during those few periods when it was fully operational, was too close and too vulnerable to the imperial authorities to serve as an incubator of rationalistic inquiry, and was in any case periodically closed and the scholars dispersed. The private academies which operated throughout the empire during the Ming and Qing periods were, during most of this period, hardly more than "cramming schools" for the imperial civil service examinations (Blunden and Elvin 145). However, the educational system in China was so distinctive, and its characteristics so fateful for Chinese culture, that it deserves particular attention.

The Educational System in China

The state in China molded intellectual life and intellectual striving to its needs through the civil service examination system, which began during the Sui dynasty (589-617), became the standard method of selecting bureaucrats during the Song (960-1275), and was revived in the Ming (in 1382).[11] This system

10 For example, in the ninth century, the Caliph Mamun sponsored the establishment of a "House of Wisdom" (*Bait-al-Hikmah*) and "to stock this official institute and library for research and translation, Mamun sent emissaries as far as Byzantium to seek out and purchase scientific and philosophical works" (Hoodbhoy 98). However, his successor reversed all of his policies: "rationalist scholars who had been cultivated in the court of Mamum, such as Al-Kindi, fled for their lives when the conservative Al-Mutawwakil took over the Caliphate. All colleges and universities were closed. Literature, science, and philosophy were indicted, and the rationalists were hunted from Baghdad" (Hoodbhoy 93).

11 By the late imperial period, the state in China had become accustomed to raising revenue by selling some of the offices in the state bureaucracy (as occurred in many pre-modern states, see Marsh). However, by the time that this practice became common, in the Qing period, the ideological functions of the examination system had already exercised a major impact on the

served the ideological needs of the empire by socializing the educated elite into a classical corpus which enjoined loyalty and deference to social and political superiors. The labour needed to master this corpus sufficiently for success in the examinations was enormous, requiring years of study and memorization (Lin, 1995).[12] The examination system undoubtedly reduced the costs of political control by ensuring that officials throughout the empire, and indeed almost all of the educated elite, were socialized in and by a common ideology (Blunden and Elvin 92). Confucianism also provided the ideological justification and philosophical apparatus for suppressing intellectual pluralism and innovation. Pluralism was always potentially dangerous for a despotic regime attempting to control a diverse population over such a wide area (Chirot 64). The combination of the mandatory state ideology and coercive political control throughout the region was decisive: "In traditional China, a territorially unified autocratic rule was effectively aided by and symbiotically combined with an equally unified system of ideological control. Its philosophical spirit was introspective, its academic scope was officially limited and exclusively ethico-political, and its basic attitude discouraged innovative practices and rationalistic inquiries" (Qian 103).

Precisely the same kind of philosophical conservatism and dogmatism existed in Europe, promulgated variously by Aristotelian scholastics, Catholic prelates, and advocates of the divine right of kings. However, the proponents of these dogmatic systems were not able to prevent intellectual diversity and rationalistic inquiry and debate from emerging in Europe, since political power was decentralized and no single political or ideological agency could exercise coercive control throughout the region. Needham correctly stated that any answer to his puzzle which focused on the effects of Confucianism in China was inadequate unless it explained why Confucian philosophy came to dominate China's intellectual landscape (Needham 1969, 150). The reasons are clear: the state in China enforced this ideology by several mechanisms, particularly through the civil service examinations and through repression of virtually all rival philosophies, while no state or authority was able to enforce such an ideology indefinitely throughout Europe. States in Europe were relatively weak

intellectual and philosophical life of China. Bureaucrats who bought their titles had to study and affect the same kinds of philosophical attitudes as those who had immersed themselves in the Confucian classics and commentaries for many years in order to earn their positions.

12 Justin Yifu Lin estimated that students had to try to memorize the Confucian classics, amounting to some 430,000 characters, which would require six years of labour at the rate of 200 characters per day; in addition, students had to read the extensive commentaries on the classics, along with assorted historical and literary works (285). He argues that the main inhibiting effect of these exams on the development of science in China was simply that the enormous intellectual labour required for success, and the rewards of such success, diverted most if not all of China's intellectuals into such efforts and away from other intellectual inquiry (see also Qian 107).

until the late Middle Ages, and political authority was fragmented among rival states, each containing a number of relatively autonomous towns and other institutions. But why did a single strong centralized state emerge in China, while political power remained decentralized in Europe?

Ecology

One of the oldest and most widely debated explanations for the character of the state in China is the "hydraulic agriculture" hypothesis. This has been explicitly linked by several scholars to the fate of science in China. Most recently, Dorn has attempted to explain the differential fate of science in various regions by adducing geographical factors, which in many locations provided conditions which favoured the rise of the "Asiatic mode of production." Grounding his analysis in sources beginning with Engels (Marx and Engels 278) that was developed into a major comparative thesis by Karl Wittfogel, Dorn argues that "hydraulic" civilizations did indeed develop in particular kinds of geographical settings — those in which large-scale agricultural engineering works such as dams, dikes, and canals could be used to increase the security and productivity of agriculture and avoid famines and ecological disasters. Such conditions occurred particularly around major river systems in otherwise arid regions. Such agricultural engineering works allowed major increases in population density and also produced food surpluses, some of which could be used to pay for corvee labour to maintain and augment these works. The state's role was - and still is (see, for example, Hinton 206) — to plan such works, and to compel and coordinate the participation of the population on a larger scale than could be managed without the state.

The state also used the surplus to pay legions of warriors and bureaucrats, thus preserving and extending its control over the population. The coercive states which evolved in these regions extended their control more deeply into local communities, and were therefore much more intrusive, than states in rainfall-agriculture regions. These "strong" states needed to continuously monitor production and conduct extractions of grain and labour, and to prevent threats to their ability to do so as a result of political resistance, and thus were more repressive and despotic. Although such states sponsored some scientific work which had practical applications, it was more difficult for intellectual diversity and philosophical pluralism, of the kind which was evidently necessary for the emergence of science in Europe, to develop under such conditions.

The "oriental despotism" thesis has been criticized on several grounds. Paul T. Cohen, reviewing studies of hydraulic societies by Leach, Stargardt, Friedman, and others, has noted that much of the agricultural infrastructure in some so-called hydraulic civilizations was maintained at the local level, without any significant state input. Where the state has played a role in the construction of large-scale water works, this construction period is also often a temporary

phenomenon which cannot easily explain the dominance of the state during long periods when no significant contruction is occuring, and when maintenance of the system occurs primarily at the local level. Further, when the state collapses temporarily during invasions or dynastic convulsions, the agricultural system may not collapse (unless it is physically disrupted by military activity). The despotic state is not necessarily generated by the needs of agriculture, since agriculture can survive without it, even though the state-organized agricultural water-works may substantially increase the surplus available to the state to fund its other self-aggrandizing projects.[13] It could be argued that the rise of despotic states is in fact more closely linked to conditions in which an agricultural state is continually threatened by nearby aggressive armies, and uses coercive methods to extract a large proportion of the agricultural surplus to support armies and to construct defenses.[14]

However, it has been widely acknowledged that where large-scale hydraulic agricultural projects were rewarded with much greater food surplus and greater security of food supply, such societies usually became despotic in the manner described by Wittfogel. Indeed, hydraulic agriculture can be viewed as a strategy by local rulers to increase their power by achieving a greater extractable surplus of food. The construction of canal systems and dykes around the major river systems in north and central China began before the first unification of China in the third century BC, and some of the rulers and officials who planned and implemented these systems are still remembered (Merson 18-20).[15] In Europe, hydraulic agriculture was not possible. Rainfall provided sufficient water for crops without state intervention, and there was no possibility of increasing the agricultural surplus through forced action by the state. The agricultural revolution which evidently occurred in Europe between about the sixth and ninth centuries AD produced a growing agricultural surplus,[16] and allowed the growth of towns in which this surplus was converted into specialized manufactured products and traded with other towns in the region (Dorn 122-24). But the state remained relatively weak and distant until the late Middle Ages,

13 Critics have also pointed out that many despotic polities developed in regions where no major hydraulic works were built, such as in Russia and Turkey (Andreski). This is not, however, a serious problem for the "oriental despotism" thesis, since it does not claim to explain all forms of despotism.

14 Such military burdens may weaken the state in the long run by making local rebellions more likely, as occurred in both Europe and China (Dorn 132-33).

15 Merson cites the official Li Bing, for instance, who is remembered for initiating the canal system around Chengdu, Sichuan, in about 250 BC (18-20).

16 The agricultural revolution in Europe comprised three innovations: the heavy plow, which greatly increased crop yields in the region; the three-field rotation system; and spring planting, especially of vegetables (see Dorn 123-24; White).

when military technology advanced sufficiently to allow a growing centralization of power in each of the major ethnic sub-regions of Europe. By that time, however, Europe contained numerous towns and cities which had already established their own political and academic institutions. Much of the surplus which could be extracted by the state was controlled privately, especially by the growing class of merchants, traders, and manufacturers in the towns. Thus one of the principal features of European society — the matrix of relatively autonomous urban-based organizations and political entities — was rooted ultimately in the ecology of the region, which led to the growth of such entities long before the state emerged to defend and aggrandize the territories in which these populations lived. By contrast, in China the cities were primarily administrative nodes of the empire, subject to full imperial control throughout most of Chinese history (Elvin 177).

However, the hydaulic agriculture explanation cannot fully explain the dominance of the state in China throughout the entire land-mass of the empire, since hydraulic agriculture or major water-works occupied only a relatively small area around the major river systems in north and central China. The regions of the empire to the south and south-east were as large and as populous as most of the countries in Europe. But agricultural infrastructure in these regions — mainly wet-rice works such as paddies, dykes, and sluices — was developed and maintained locally. There was no significant direct role for the state in this type of agriculture, nor did the state build major water-works or canals in the south comparable to the Grand Canal system for transportation of grain from the Yangzi region to the imperial capital (Blunden and Elvin). Much of the labour involved in water-control for wet-rice agriculture in southern China was organized and controlled at the village level, as critics of the oriental despotism hypothesis have pointed out (Merson 28). Perhaps it could be said that the state nevertheless played a coercive role by extracting some of the surplus and thus compelling villages to maintain a high degree of local social control in order to maintain agricultural productivity and satisfy state demands for grain, even if that social control was ultimately enforced mainly by one's kinsmen, or by wealthy local landowners (Elvin 82).[17] But we may still ask: why did these regions not develop their own state systems separate from the state-system which evolved in the regions of "hydraulic agriculture"? Why did the state which developed in north and central China come to dominate such a large region despite the lack of any coercive role throughout much of this region in the

17 Elvin writes of water control: "many of the new irrigation projects undertaken in Sung times were the work of manors, or combines of manor-owners; and the control of the permanent staff who ran these gave them enormous influence in their localities. The state was always trying to supervise the allocation of water and the levy of labour for repairs, but those in immediate charge were invariably the wealthiest landowners, and water-control organizations of this period were often simply a further aspect of manorial power" (82).

production of greater agricultural surplus? The repeated conquest and reunification of the entire region of what is now China had enormous implications for intellectual life in China.

The first conquest and political unification of China may have terminated a period of growing intellectual pluralism within the contending pre-imperial states, and portended the significance of empire for intellectual development in China. Prior to the Qin conquest, late pre-imperial social and political development within the states of the period evidently included an increasing division of labour, the growth of professional and educated classes, and diverse political discussions within and between competing schools of thought (Bodde 178-81). The intellectual consequences included development of new debating techiques and creation of academies of learning by several states. The reaction of those who followed Confucius (for instance, Mencius) was to lament the disputation and disunity which they observed to be increasingly characteristic of intellectual life in the contending states. The Qin marked a sharp end to these developments, as was noted later by the historian Ban Gu (AD 32-92): "When the Ch'in came, it was unhappy about this state of affairs, and so [in 213 BC] burned and destroyed written documents in order to make ignorant the black-headed people" (qtd. in Bodde 181). During the next 1,900 years, the imperial state partly or wholly disintegrated many times as a result of internal rebellions or invasions from states in the north and northwest, but the empire was always restored by military conquest. None of the temporary states which coalesced during the intervals between disintegration and reunification were able to survive long enough to acquire their own distinctive intellectual or political traditions, although some regions nurtured memories of their temporary independence.[18]

It is possible that during the Song dynasty, and particularly during the Southern Song (1126-1279), parts of the area under Song control were developing a form of civilization which might have incubated both capitalism and modern science. The wealth and influence of merchants was evidently growing, as was the reliance of the imperial treasury on the taxes and revenues which could be extracted from their activities, including overseas trading, after the loss of much of the agricultural land north of the Yangzi to the Jin Tatars (Merson 60-61). Meanwhile, a relatively more cosmopolitan and relatively more empirical intellectual culture was developing in the cities. China during this

18 The Lingnan region comprising the current provinces of Guangdong and Guangxi, for example, has had almost enough geographical, ethnic, and linguistic distinctness to become politically autonomous, and has achieved several periods of autonomy since its initial conquest by the Qin in the third century BC. However, it was too vulnerable to invading armies from the north, both from the sea and from the land, and thus has been reconquered and reabsorbed into the empire after each short-lived period of independence. Lingnan scholars have attempted to explore and rehabilitate these periods in their history whenever they were able to do so, with much delicacy so as to avoid arousing the suspicions of the imperial authorities (see Lary).

period may bave been approaching "the threshhold of a systematic experimental investigation of nature," particularly with regard to medicine and pharmacology (Elvin 178, 188-90). If this is the case, then the Mongol conquest and reunification of China was disastrous for science. The Ming conquest and reunification produced an even more despotic and conservative regime. The technological and intellectual stagnation of China began, according to some scholars, in the Ming (Huang). It is possible that some of the late-Ming scholar-bureaucrats were beginning to develop a more rational-empirical approach to studies of the natural world, particularly as a result of encounters with some of the scientific theories, methods, and devices brought into China by the Jesuits. However, the Manchu conquest brought disruption and downfall for many of these officials; some of them died during the conquest, or refused to serve the new rulers (Spence 148-54). Meanwhile, the new regime was capable of suppressing technological writings by some of these officials for the most trivial ideological reasons.[19]

The principal significance of the political reunifications, however, was not in the particular character of each regime, but in the impact of reunified and centralized imperial power on intellectual developments within the Chinese land-mass. Although some of the dynasties were more despotic and repressive than others, all of the dynastic regimes pursued a policy of ideological control for the sake of political stability, and all of them were able to identify and punish dissidents and free-thinkers anywhere within the empire. Scholars who wish to qualify this picture of ideological surveillance and repression have tried to highlight those figures who produced innovative non-Confucian or anti-Confucian philosophies, such as Wang Yangming (1472-1529) (Lin 282). But the typical dismal fates of such figures and their philosophies merely confirms the ability of successive regimes to dominate and control intellectual life in the empire (Blunden and Elvin 145).[20]

19 For example, a technical treatise printed and well-received in 1637 was not reprinted after 1644, evidently because it contained a slighting reference to the Manchu homeland (Spence 150).

20 Lin writes that Wang Yangming "stressed heterodox intuitive knowledge, the intrinsic equality of all men and the unity of knowledge and conduct, all in sharp contrast to the official conservatism.... His teaching initiated a powerful social movement and numerous followers and admirers established hundreds of private academies ... to disseminate Wang's philosophy (283). Blunden and Elvin however, observe that "in the 16th century, under the influence of the philosopher Wang Yangming, [the private academies] had showed a spurt of independent intellectual life, [but] ... in 1579 this led to the partial closure of private foundations at the instigation of the practically minded and intolerant statesman Zhang Jucheng ... [who] feared their threat to state orthodoxy and their involvement in factional politics" (145). Thus, with regard to Wang and a few other frequently-cited innovators, "so far from being a proof of the vitality of late traditional culture, they show the opposite: its capacity to suppress and blot out lines of thought that did not accord with its already established predispositions" (Blunden and Elvin 146).

By contrast, Europe has been politically fragmented for more than a thousand years. This political fragmentation has been important for the history of science for a number of reasons. First, it has meant that the states in Europe were in chronic competition with each other in regard to weapons and military engineering. Such competition led most of these states eventually to value and reward technical expertise and innovation, in the conviction that the state could derive advantages from having better technicians and engineers than rival states. The multi-talented polymaths of the late Middle Ages could "hawk their talents around the courts of Europe" (Merson 70), seeking the highest bidder. Experimental science was supported to a hitherto unprecedented degree because it was perceived as being capable of generating improved techniques which could contribute to such an advantage (Wuthnow).[21] The legimitation of science did not occur only in religious terms, such as "studying the marvelous design of God's universe," as the Puritans argued, but also included frequent references to the practical benefits of scientific progress (Merton).

It should be noted here that science at this time did not often have immediate practical applications, and the integration of science with industrial technology was not well-established until the nineteenth century. Rulers did not fail to notice this lack of practical application, and declined to fund scientific work generously for this reason (Dorn). Many of the rulers and some of the scientists also believed that astrology and alchemy were part of the scientific enterprise and could provide practical benefits. It was only in the light of later scientific findings and theories that such beliefs began to seem absurd. Despite the shortcomings of early scientific work and the lack of practical applications for most of it, sixteenth- and seventeenth-century regimes were aware of the potential uses of scientific investigations in their competitions with each other, and tolerated the activities and associations of the scientists partly for that reason. Some scientists of the period clearly worked to enhance such awareness. Most of the states in Europe patronized or tolerated universities, while the monarchs of both England and France eventually supported the establishment of scientific societies. More subtly, the political fragmentation of Europe allowed intellectuals to escape persecution or hostile attention from their own rulers by simply crossing into a neighbouring state where their work would be tolerated

21 For example, when news of the invention of the telescope reached Galileo, then (1609) at the University of Padua in the Venetian republic, he immediately experimented with telescopes to find a model which would be useful for the maritime and military needs of Venice, and was rewarded with a salary increase — although later rescinded when the Venetian senators discovered that other states also had the telescope (Shea 480) — and with academic tenure (Goodman and Russell 103).

(Wuthnow).[22] If one state happened to have an arch-conservative ruler, a neighbouring state might have a relatively liberal regime. No doubt rulers were less aggressive in their persecutions, knowing that intellectuals could escape so easily to rival states.

Political decentralization also meant that there were groups of scientists more or less officially supported in each of these states, competing for fame by producing more striking findings or techniques, and yet also communicating with each other through publications which were carried throughout Europe by travellers and academics (Withnow). The flow of information was facilitated by the flow of students and scholars across state boundaries, travelling to whatever universities and scholarly communities interested them most. Indeed, some universities competed for students by offering studies of what was prohibited elsewhere.[23]

There were of course agencies and regimes which wished or attempted to maintain the kind of ideological hegemony and control exercised by the Chinese imperial regime. The Catholic Church, in particular, attempted to maintain control over belief throughout Europe, by threat of trials and executions if necessary, and exercised considerable political power over rulers in some of the states, just as the Muslim Ulama were able to do in some Muslim states. However, the rise of the nation-state with its own universities and its communities of relatively protected intellectuals eventually doomed the efforts of the Church. The Reformation was not so much a cause of the rise of science (Mason) as a perfect illustration of the liberating effects on intellectuals of political fragmentation. In short, the political fragmentation of Europe, and the political unity of China, helped to produce the vastly different fates of science in the two regions.

Why was political power centralized in China, while a much more decentralized and fragmented system of political entities developed in Europe? Ultimately, the answer lies in the realm of geography. Europe is comprised of

22 For example, Kepler, persecuted in Tübingen, migrated to Austria; a group of seventeenth-century scientists gathered around the Duke of Northumberland fled England during the revolutionary period and received patronage in France; the Dominican philosopher and utopianist Tommaso Campanella (1568-1639) was imprisoned for his heretical writings, but later escaped to France and was patronized by Richelieu. Even some of the cases of severe repression of intellectuals illustrate the point: Giordano Bruno (1548-1600), who argued for many solar systems and an infinite universe, was executed for heresies only because he made the mistake of going to Venice, which handed him over to Rome. He was involved in controversies wherever he went, but was not in danger in most of the European cities in where engaged in philosophical debates and disputes, and indeed would not have been in danger in Venice either if he had arrived a few years later (Goodman and Russell; Wuthnow).

23 For example, the University of Toulouse in the thirteenth century attempted to attract more students by advertising the study of books banned in Paris (Goodman and Russell 27).

a number of sub-regions, each of which is relatively protected by substantial geographical barriers such as mountain ranges, major rivers, bodies of water, or dense forests. These regions evolved separate languages and ethnic cultures, and were relatively difficult to conquer and hold within a unified empire. With rainfall agriculture throughout most of this region, and no role for the state in producing surpluses, most of these regions developed their own political institutions, which formed the basis for resistance to later attempts by other imperialistic states or agencies to impose control over them. Most of these regions eventually developed into nation-states. Thereafter, potential conquerors were deterred, or defeated, partly because geography provided numerous natural defenses against conquest and prolonged centralized control over the region.

In a subsequent paper, I plan to elaborate by describing the geographical routes through which the sub-regions of China were invaded and controlled, and the geographical difficulties which led to failures or inhibition of conquest and control in Europe. Here only a brief sketch can be attempted. We may note that the British Isles were surrounded by water; France was partially protected by seacoasts, the Pyrenees, the Alps, and the Rhine; Spain was protected on three sides by water, and on the fourth by the Pyrenees; Italy was protected similarly by water and by the Alps; and Germany was partially protected by a patchwork of mountains, rivers, and dense forests in the south and west, and by the seacoast in the north-west. None of these areas was immune to invasion, and all were successfully invaded at one time or another during the past two thousand years. But since all the states in Europe presented such difficulties, no state was able to dominate and conquer nearly or all of the others, thus achieving the power to concentrate all the resources of the region to bring the last recalcitrant state back into a regional empire. States also formed alliances to protect each other from invasion by other states, which further inhibited regional unification. The few temporary empires quickly disintegrated under the difficulties of holding the entire region under a single imperial system.

In China, by contrast, imperial control over the region was maintained for most of the past two thousand years, and was repeatedly reconstituted by military conquest whenever the empire distintegrated due to internal rebellions or invasions from the north or north-west. Regions such as Lingnan could never find military allies to help protect themselves from invasion by sea or by land and were always reabsorbed. The only part of the region which has been part of the empire but managed to break free was Taiwan: it has just enough geographical separation from the mainland to be vulnerable to external conquest (by the Dutch, and later, by Japan), and for the same reason, to escape reconquest and reabsorption into the empire, especially as in the modern period it has acquired a military ally which helped the island to maintain a precarious independence.

The geographical limits to the expansion of the empire have been apparent in the history of attempts by the various Chinese imperial regimes to conquer

and hold neighbouring regions. Vietnam and Korea were near the limits of the imperial regime's ability and determination to surmount geographical obstables to achieve political control, and although northern Vietnam was under Chinese rule for a long period, both areas have managed to escape the imperial embrace for the past thousand years.[24] Japan is too well-protected by geography to be seriously threatened by any non-industrialized state. At the same time, none of these regions presented any serious threat to the imperial regime, and thus they did not provide the stimulus of chronic military and commercial competition, largely because China was simply too vast and its population too numerous to be seriously challenged by the weak and remote minor states on its periphery (except of course by land in the north and north-west, where the terrain provided no natural barriers and offered an easy route of invasion for cavalry). China was relatively isolated from other potential major competitors by high moutains and vast deserts in the west and south-west, by dense jungle and mountains in the south, and by a vast ocean on its eastern sea-coast. Once it had reached the practical geographical limits of its territory (given current military technology and the nature of the populations on its periphery), the empire could concentrate on political stability and political control, without the necessity to tolerate intellectual pluralism with all its dangers, and with the means to pursue critics and dissenters anywhere within the vast geographical scope of imperial control.

To this picture, we must add one final component. The competition within Europe was not only between states, but also between private organizations engaged in production and trade of goods for profit. In addition to the intense competition between states, there was thus also an intense economic competition between corporations of private citizens, whose wealth depended on better techniques and ultimately, better knowledge of nature. No such intense competition occurred in China. This competition helped to provide more of the rewards for better knowledge of natural phenomena which helped to stimulate the interest of academics in the universities of Europe. It also may have affected the very terms in which natural phenomena were studied, by introducing mathematical calculation into the intellectual life of the growing middle classes engaged in such private manufacture and commerce, and thus ultimately into the curriculums and the methods of the "natural philosophers" working in the universities and other institutions of learning.

24 In part, the independence of Korea and Vietnam is not purely a matter of geographical barriers alone, but a result of the costs of surmounting such barriers relative to the benefits for the empire of doing so. If China-based empires could have reaped large benefits (political, financial, or military) from conquering and holding Korea or Vietnam, there is little doubt they would have done so. Unssuccessful and costly invasions of both regions, however, demonstrated to the imperial regimes (both Mongol and Chinese) that there was not sufficient benefit from such conquests to justify the high costs.

Capitalism and Science

A number of scholars link the rise of modern science in Europe to the rise of capitalism. Joseph Ben-David suggested that the growing merchant-capitalist class in Europe helped to promote a calculating rational-empirical approach to solving problems and getting things done, and thus helped to stimulate the growth of empirical science in the universities. E. Zilsel and Needham believed that the development of mathematics and its application to problem-solving in Europe owed a great deal to the stimulus of commercial problems and concerns, and to the quantitative calculations of commerce, trade, investment, and manufacturing which became increasingly common as capitalism developed. Needham concluded that "apparently a mercantile culture alone was able to do what agrarian bureaucratic civilization could not - bring to fusion point the formerly separated disciplines of mathematics and nature-knowledge" (1972, 44, 1969, 211). Robert Merton showed that the scientists and inventors of the seventeenth century tried to legitimate science to their contemporaries, with considerable success, by arguing for its practical benefits. The work of Merton, Zilsel, and Johnson shows that some of these scientists and inventors did interact with those engaged in commerce, navigation, and the military, and were stimulated and challenged by the problems raised in these sectors of the society. Capitalism evidently helped to break down the barriers which formerly existed between the educated elite and the technicians and craftsmen, drawing educated persons into commerce and industry, and bringing high material and social rewards to successful inventors and their patrons.

It is generally agreed that China did not develop capitalism and was not close to doing so at any time prior to the nineteenth century. Despite recent research on trading relations, the accumulation of capital, and the use of various kinds of instruments to facilitate trade, this conclusion has not been significantly modified. China was evidently not approaching an economic transformation to capitalism in the late Ming, since it still lacked credit and banking institutions, insurance, and the matrix of civil laws and legal proceedings needed to anchor the complex commercial relations of capitalism (Huang 173). The lack of state involvement in setting up such a legal apparatus is due in part to the fact that merchants and merchant guilds never achieved the political power or influence in China which they developed in Europe (Needham 1974, 107). The link between capitalism and the rise of science is circumstantial. Both developments occurred in the same region of the world, and at about the same time. The influence of capitalism on the rise of science must also be considered indirect. But if we grant, for the moment, that capitalism may have stimulated the rise of science, what explanations can be given for the rise of capitalism in Europe, and the lack of such a development in China? Weber attempted a culturalist explanation. However, he admitted that some elements of Protestant asceticism, which he thought had facilitated capitalism, may have been influenced by the

socio-economic environment within which Protestant asceticism emerged, and thus that changes in this socio-economic environment may have been primary after all.

Discussing the rise of capitalism is beyond the scope of this paper. However, I suggest that there were similar conditions underlying both the rise of capitalism and of modern science in Europe, and that there were also similar conditions underlying the lack of either in China. The key factor, once again, was political centralization in China, and political decentralization in most of Europe during the incubation period of both capitalism and modern science (that is, roughly from the eleventh to the seventeenth centuries).

Conclusion

My analysis of the structural conditions for the rise of modern science allowed a comparison of China and Europe in terms of these conditions: The most important conditions were present in Europe, partly or wholly absent in China. I proposed several explanations, as follows:

1) The chronic commercial, military, and maritime competition among contiguous but independent states in Europe, and the lack thereof in China.
2) Numerous relatively autonomous nodes of inquiry — the universities — in Europe, and the almost complete lack of such settings in China.
3) The agricultural system of Europe favoured the development of relatively autonomous towns and local institutions prior to the development of centralized states in the region, while in China, strong and intrusive states developed in the major river valleys, prior to the growth of towns, as a result of the opportunities to extract much greater agricultural surplus through large scale hydraulic-agriculture projects using taxes and corvée labour.
4) The geography of China, unlike that of Europe, did not favour the prolonged survival of independent states. Instead, China's geography facilitated conquest and unification over a vast area, followed by long periods of relative stability under imperial rule. The resulting state system suppressed most of the conditions required for the emergence of modern science, particularly, the existence of relatively autonomous nodes of inquiry in which critical analysis of theories about the world could occur. A partly independent factor was the development of competitive commercial and industrial capitalism in Europe during the late Middle Ages. However, there are links between this development and the above-mentioned structural factors. Capitalism emerged from a relatively decentralized political system in Europe in which agricultural surpluses were converted into privately managed and traded goods; the control of the imperial state over the economy in China, meanwhile, largely prevented the emergence of capitalism.

The model sketched above is certainly oversimplified. However, one of the advantages of this kind of account is that it escapes the circularity which often creeps into explanations which do not go deeper than social or cultural

differences. Such explanations can always be challenged with the further question "Why were Europe and China different in regard to those social or cultural factors?" Explanations rooted ultimately in geography and ecology, however, have reached bedrock. Using the work of a number of structuralists, this paper has proposed a relatively parsimonious theory to explain the rise of modern science in Europe, and the lack of such a development in China.

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