

Why Was China Trapped in an Agrarian Society--An Economic Geographical Approach to the Needham Puzzle

Guanzhong James Wen¹
Department of Economics
Trinity College
james.wen@trincoll.edu

Abstract

Why the scientific revolution only took place in Europe is an important part of the Needham Puzzle. This paper argues that before the world started to globalize, the differences in the geographical endowments of populations were the most important constraints to their long-term production and consumption. The paper uses this central hypothesis to explain the sharp contrast between the flourishing Song and the stagnant Ming and Qing. During the Song dynasty, despite the fact that China lost a significant amount of arable land to invading nomads as its population peaked, China witnessed a higher urbanization level, more prosperous commerce and international trade, and an explosion of technical inventions and institutional innovations. However, after China significantly improved its man-to-land ratio in the period after the Song only to find itself induced deeper into the agrarian trap, resulting in reduced urbanization, withering foreign trade, a declining division of labor, and stagnant in technology.

Keyword: Needham Puzzle; Scientific Revolution; Geographical Endowment
JEL Classification N 15, O 31, R 12

¹ I want to thank A. Grossberg for editing help, and Trinity College for financial help. All the remaining errors are exclusively mine.

I. Introduction

1.1 What is a more interesting question?

China has been remarkably successful in maintaining a high rate of growth for almost three decades. This momentum and performance lead to a natural question: How soon will China surpass the USA to become the largest economy in the world? Given China's geographical and demographic size, it is not that surprising that China may succeed in accomplishing this in three or four decades, restoring China to a position it lost not too long ago. Given China's large and still growing population, even if China only manages to reach a per capita income of one fifth of that of the US, China still can be the largest or second largest economy in the world.²

An academically more interesting as well as more challenging question was first raised by Joseph Needham and has mesmerized many scholars since then. In his multi-volumed *Science and Civilization in China* Needham documents in great detail what China achieved in technology, as exemplified by its advanced agricultural technology, its numerous inventions including gunpowder, the magnetic compass, paper, moveable type printing, its highly developed mining, iron and steel production technology, and its ocean-going ship building industry. China also was the first to learn how to manufacture sophisticated products such as porcelain and silk. Needham concludes that China was the leading nation in technology over fourteen centuries prior to the 16th century (1981 p3).

² In 2005, China's per capita GDP was US\$1,709, compared with US\$42,000 of US, and US\$35,757 of Japan. In other words, China's per capita GDP was about 4% of that of the US, or about 5% of that of Japan as recently as in 2005 (see http://en.wikipedia.org/wiki/People%27s_Republic_of_China; http://en.wikipedia.org/wiki/Developed_country#America; and <http://en.wikipedia.org/wiki/Japan> Dec. 27, 2006).

China's technological achievements during this period explain to a great extent what Angus Maddison has documented in his book *The World Economy*. According to Maddison (2001, Figure 1-4, p.42), not only the size of China's economy, but also its per capita income, was higher than that of Europe from the fifth to the fourteenth century.³ However, by the mid-twentieth century, not only had China's per capita income fallen far behind that of Europe, but it had also shrunk to less than three quarters of its own 1820 level (Maddison 2001, p.117).

Combining the findings of Needham and Maddison, we can conclude the following: First, from at least the beginning of the first century AD, until the beginning of the 19th century, China was the largest economy in the world. Second, from the second century AD to the 16th century China led the world in technology. Third, from the 5th to the 14th century AD, China led the world even in per capita income. For these reasons it is more interesting to ask how China managed to achieve and sustain this technological preeminence for so long, and why China first lost the title of highest per capita income in the 14th century, then lost the technological preeminence after the 16th century, and finally not only lost the title of the largest economy in the beginning of 19th century, but became one of the poorest nations in the World.

As China is poised to become the world's largest economy again within a few decades, an important question is: this time will China be able to also lead the world in technology and in per capita income? For China to achieve these more difficult goals, what must China do institutionally and technologically in addition to achieving economic growth? If we understand how China managed to reach global preeminence historically, we might be in a more enlightened position to project China's future.

³ Maddison uses 'levels of income' to refer to per capita income (see p.117).

1.2 The Organization of the Paper

Section II discusses the Needham puzzle, its inherent four issues, and the early efforts to resolve them. Section III introduces the central hypothesis of the paper after discussing the economic implications of geographical endowments as economic constraints. Section IV answers the first two Needham issues using historical evidences from the ancient Middle East and Greece. Sections V and VI address the third and fourth Needham issues by showing why China was trapped in an agrarian situation until the modern era when it became poised to take a new trajectory during the Song dynasty. Section VI concludes the paper.

II. Early Efforts of Resolving the Needham Puzzle

2.1 The puzzle and its inherent four issues

Bewildered by his own findings about China's protracted technological domination and its sudden dissipation, Needham summarizes his famous puzzle in *Science in Traditional China* (1981):

“...the question [is] why modern science, the ‘new or experimental’ philosophy of the time of Galileo, had arisen only in European culture and not in Chinese or Indian....a second question hiding behind that first one: namely, how could it be that the Chinese civilization had been much more effective than the European in finding out about Nature and using natural knowledge for the benefit of mankind for fourteen centuries or so before the scientific revolution?”⁴

⁴J. Needham, “Science in Traditional China” , Cambridge, Massachusetts: Harvard University Press, 1981, p3. There are numerous versions Needham puzzle phrased by Needham at different stage of his research. The above-mentioned represents the best

Here Needham realizes the difference between sciences (which are experiment-based) and technologies (the discovery of practical knowledge about nature and its application to the benefit of mankind). According to Mokyr (2003), the difference between technology and its underlying epistemic base is as follows: “technology consists of *techniques or routines* which in the final analysis are sets of instructions—tacit or codified—that tell people how to produce. Yet these routines rest on some underlying body of ‘useful knowledge’ about the natural phenomena and regularities that make them possible.” Mokyr (2002) also discusses “prescriptive knowledge” and “propositional knowledge”. As Varian (2004) explains in his review of Mokyr’s book, “[p]ropositional knowledge is knowledge (or beliefs) about natural phenomena. Prescriptive knowledge is knowledge about techniques—they may work, even if no one knows exactly why.”⁵ Borrowing Mokyr’s terms, it appears that what Needham really wants to say is, China was good at developing technology, or prescriptive knowledge, but not good at developing sciences, or propositional knowledge that can hold water when examined by logic or facts, or tested by experiments.

A closer look reveals that the Needham puzzle actually contains four issues (hereinafter the Needham issues). First, why was China not a leading nation in the world before the 2nd century AD? Second, why did modern science or the experimental philosophy in Needham’s words, only emerge from European culture? Third, why did China become a leading nation only in the field of practical technique during the following 14 centuries?

phrased one at a later stage of his long life shortly before his health started to deteriorate in the mid-1980s.

⁵ According to Mokyr, “[a]n advance in propositional knowledge is a discovery, while an advance in prescriptive knowledge is an invention.” (Varian 2004).

Fourth, why from the 16th century on, did China become a backward nation again even in practical technique?

2.2 Earlier explanation

The hypothesis of a high-level equilibrium trap put forward by Elvin (1973) is still influential today.⁶ According to him, the steadily rising man-to-land ratio led to surplus population and reduced social surpluses. Consequently, labor costs fell continuously relative to the cost of capital goods. This reduction in the price of labor relative to capital, therefore, deprived China of demand for labor-saving technology, and slowed down China's technical progress (Figure 1).⁷ I will come back to this hypothesis later. Justin Lin has made significant progress trying to resolve the Needham puzzle. In his 1995 paper he identifies two different modes of invention and their respective main characteristics. His hypothesis can be summarized as follows. Before the 16th century, most technological inventions were experience-based, hence population size was the main variable determining the pace of inventions. As the most populous nation, China had the richest collective experience, and therefore should be expected to have an edge over other nations in technological breakthroughs. After the 16th century, technological innovation in Europe was experiment-based, and the frequency of experiments instead of population size became the main determinant of technical progress. China failed to switch to this new mode of invention, and has lagged behind Europe since then. Both of the invention modes rely on trial and error to find new knowledge. But the first mode does not use theories as guidelines. It depends instead on cumulative experiences. Therefore, population size matters. Under the second mode, where theories are used,

⁶ See, for instance, in his 1998 book and 2006 article, Landes cites Elvin numerous times.

⁷ It is numbered Figure 4 in Elvin's 1973 book. Elvin indicates on p312 that his figure was after R. P. Sinha.

breakthroughs can be made much more rapidly by raising the frequency of experiments to exclude ungrounded hypotheses or less desirable results. Therefore, the importance of population in invention is reduced.

Lin's hypothesis is supported by Diamond (1997). He has established that only limited localities on earth had the carrying capacity to support a relatively large population cluster⁸ at the early stage of human evolution before the agricultural revolution. He has also established why a population cluster must be sizable before it could evolve into a civilization.⁹ Different from culture, which any population cluster could develop, a civilization by definition, must have a writing system, a hierarchical social structure, and an urban center. The emergence of a civilization, thus characterized, would have an edge over other human clusters in terms of the speed at which wealth, knowledge, and technology can be accumulated and then diffused among a relatively large number of people.

However, Lin's hypothesis cannot answer the following remaining issues. First, why did the Greek civilization reach such a high level of technology and knowledge in almost all the fields of human activity with a relatively small population size? Second, why did Europe succeed in finding the new invention mode while China failed? Third, when China's population size became much larger after the mid-Ming, and particularly after the mid-Qing relative to that of the Song, why did China become so quiet in invention

⁸ Population cluster or human cluster in this article refers to any autonomous community. It could be a group of people, an extended family, a tribe, a tribal union, a kingdom, a city state, or an empire.

⁹ According to Mokyr (1999), Diamond is talking about the importance of population density instead of population size. The two terms are not necessarily equivalent. If we assume the boundary of a civilization remains unchanged throughout history, then population growth automatically leads to rising population density and population size. If its boundaries are not stable, as is often the case in the real world, then the rise in population density is not automatically equivalent to an increase in population size. Losses of territory may lead to much raised population density as a result of an influx of refugees from the land lost to the invading enemy. However, territorial expansion into formerly sparsely populated area will decrease the nation's overall population density, but increase, however slightly, the total population size.

and innovation compared to the Song and earlier periods when China's population was much smaller? Obvious, Lin leaves a number of questions to be answered.

Landes (2006) confirms that China was indeed a promising nation technologically by saying, “[t]he one civilization that was in a position to match and even anticipate the European achievement was China.” The same paper points out, “[a]s late as the end of the first millennium of our era, the civilizations of Asia were well ahead of Europe in wealth and knowledge.” But Landes rejects (in my view, correctly) the “would-be orthodoxy” or its variant “history-as-accident” advocated by the “sinophilic school” (Landes 2006). According to this school,¹⁰ China would have been ready to launch its own Industrial Revolution, had the European invasion led by the Portuguese not interrupted the process; it was just good luck or pure accident that Europe went ahead of Asia in technology and science.

In his monumental book entitled *The Wealth and Poverty of Nations* (1998), Landes documents in great detail the widening disparity between Europe and China in their attitude and culture towards science and technology. While Europeans showed great curiosity to anything new, mechanical, accurate, labor-saving, or efficient, Chinese were indifferent to say the least. They were often contemptuous or even hostile if the novelty had a foreign origin suggesting the inferiority of the indigenous culture and civilization. Landes also shows in the same book that while Europeans learned to manage and accumulate knowledge to avoid repetition and oblivion, the Chinese failed. The consequent technical stagnation or even regression was a common occurrence in China's long history. In his 2006 article, Landes argues that to keep its leading role in technology,

¹⁰ Landes (2006) lists Abu-Lughod (1989), Frank (1998), Pomeranz (2000), and Hobson (2004) as the representatives of this school of thought (see p21 of his article).

actually “China had two chances: first, to generate a continuing, self-sustaining process of scientific and technological advance on the basis of its indigenous traditions and achievements; and second, to learn from European science and technology once the foreign ‘barbarians’ entered the Chinese domain in the sixteen century. China failed both times.”

Landes puts the blames on China’s cultural arrogance and conservatism. In my view, it is true that the traditional Chinese culture did not encourage curiosity, originality, or creativity. Instead, it encouraged conforming to traditional values and customs. The Chinese intellectuals always longed to return to the life style and moral standards of the high antiquity. Therefore, Landes is right to criticize the Chinese culture. Nevertheless, a legitimate question is in order: why did China develop such a cultural attitude of, in Landes’ words (2006), “superior indifference” to novelty, especially novelty with a foreign origin?

While Mokyr (1999) highly evaluates Landes’ 1998 book, he points out in his review that “[e]conomists will find the emphasis on culture at the expense of institutions surprising.” According to Mokyr, “[i]n addition to culture, there was geography. It is always logically tempting to rely on geography because by and large geography is truly exogenous. Culture, technology, trade, institutions, and government, all are determined by each other in a logically overdetermined system. But geography, climate, soil fertility, and accessibility are all largely given, and so they determine economic growth but are not determined by it.” Actually, in his 1998 book, Landes devotes the first two chapters to introducing the importance of geographical inequality across nations and how this natural inequality goes a long way to explaining the differences in nations’ attitudes to work

ethics, and the consequent differences in economic growth. Surprisingly, Landes does not develop this line of thinking in his 2006 article.

Equally interesting, Mokyr himself also does not pursue this line, although in his 2003 paper entitled *Why was the Industrial Revolution a European Phenomenon?*, he seems to refer to a geographical reason.¹¹ After reviewing many historical facts from China, Mokyr concludes that China did accumulate a rich pool of useful knowledge. In his words, “[a]s late as the middle of the seventeenth century, the differences between the epistemic bases on which technology rested in the West and China was probably not large.” When addressing the later divergence, he avoids geography by saying it is the “culture and institutions that generated and diffused useful knowledge in Europe and the institutions that supported it, eventually developed characteristics that allowed the epistemic bases of technology to become eventually ever wider in part as a result of the techniques that it supported.” A legitimate question for Landes and for Mokyr is, after its technological blossoming during the Song, why did China suffer from “magnificent dead ends,”¹² rather than developing cultural and institutional characteristics similar to those of Europe? Have we exhausted the explanatory power of geography?

III. Geographical Endowments and Long-term Economic Growth

3.1 Geographical endowments as important budget constraints

Landes is certainly not alone in turning away from geography, as a determinant of long-term growth, as Mokyr (2006) notes. Economists have stayed away from this seemingly treacherous factor, except for a few such as Heckscher, Ohlin, and Krugman. The

¹¹ Strictly speaking, Europe can only be a geographical concept instead of racial or cultural concept, as there is no one European race or one European culture, but there is only one Europe as a graphical concept.

¹² Mokyr (2003) quoting from Landes.

Heckscher-Ohlin (H-O) model uses the difference in natural endowments of various factors of production across nations to explain the origin of international trade. Among contemporary economists, Krugman most enthusiastically emphasizes the relevance of geography in economic studies. For example, in his book entitled *Geography and Trade* (1991), he criticizes the neglect of geography in economics. However, because the impacts of geographical factors are difficult to quantify, economists often assume these factors away.¹³

Let's see why geographical endowments were of great importance, especially at the early stages of human development. In economics, we assume that a decision maker, be it a person, a firm, or a community, has a utility function, a production function, and a number of budget constraints. We can argue that when the early Homo sapiens were migrating out of southeast Africa, there should not have been significant differentiations in their culture, preferences, technology, production, and social organizations, since these Homo sapiens had evolved in the same environment up to then. However, once they were re-settled by chance in different geographical locations, the geographical environments would have imposed various constraints on their patterns of production and consumption.

Hence, it is safe to assume that all human clusters at this early stage had similar utility and production functions. What made them different were the different budget constraints they faced. Among the explicit inputs in a production function, including

¹³ See Krugman, 1991, page 99-100. Unfortunately, by assuming away impacts of geography, all economies, small or large, reduce to a single point. All distances disappear too when transportation cost is assumed zero, and flow of information is assumed perfectly smooth. Increasing returns to scale, one of the main sources of endogenous growth, is also often conveniently swept under the rug because it is difficult to incorporate into the traditional general equilibrium model, which is based on constant returns to scale assumption.

land, labor, capital, and technology, land was the most important. This is because at very low productivity, there should not be significant differences across human clusters in accumulations of human and physical capital. Lack of social surplus precluded the emergence of a leisure class who could afford to devote time and resources to accumulating knowledge. At this early stage, even the size of population was mostly determined by the initial carrying capacity of the land. Therefore, at least two important arguments in a production function, i.e., land and labor, were actually geographically determined at first.

In this paper I will use the term “geographical endowments” to capture many implicit factors that the term “land” does not convey, such as topography, ecology, fertility of land, climate, location, and underground minerals.¹⁴ Since these implicit factors are all related to geography, and affect a population’s production and consumption costs, they should be included in budget constraints. It is mainly the differences in these geographically based budget constraints that shaped the path of development of particular human clusters. Therefore, information about geography is highly relevant in projecting the long-term development trajectory of particular population clusters and the limitations they faced.

These geographical constraints must have shaped the way an early human community consumed, produced, and behaved.¹⁵ Each human community would have been induced or forced by geographical conditions to embark on a certain path of social, economic and

¹⁴ This list is certainly not exhaustive. For example, whether a plain was covered with or grasses could be important in determining why the Chinese civilization emerged much later than the Middle East civilization.

¹⁵ They would choose herding if living in grassland, hunting if living in a forest, fishing if living close to water, gathering and later farming if living on a fertile plain, trading if living in a strategic locality, or warring if living in a barren environment that was next to a rich but vulnerable target.

cultural evolution. In this sense, the differentiations in culture, preferences, tastes, technology, behavior, organizations, and institutions must have developed at a much later stage, and been shaped by silent but dominating geographical factors. The different geographical factors, the ultimate exogenous variables, explain to a great extent why the same Homo sapiens eventually evolved into different peoples with different collective preferences, cultures, technology, behavior, organizations, and institutions.

3.2 New light shed by the H-O model and the Rybczynski Theorem

The H-O model is mostly used in international trade, but actually has deeper implications relevant to endogenous urbanization and growth, and to the Needham puzzle. The model is mainly based on the geographical fact that natural resources are not evenly distributed across the world. Comparative advantage comes from the differences in factor proportions, or in factor availability across nations. Within this framework, Rybczynski proves that when an economy loses a certain amount of its endowment of one factor of production, the sector that does not use this factor intensively will expand at the expense of the sector that does use this factor intensively.

Let's look at the implications of this theorem. Assume an economy has two sectors, one labor-intensive (say textile) and the other land-intensive (say agriculture), and for some reason the economy loses some of its land. The immediate effect is a worsening man-to-land ratio, which leads to the decline of the land-intensive sector. Meanwhile, the labor-intensive sector will expand by gaining land and labor at the expense of the land-intensive sector. Firms in the labor-intensive sector, by the very nature of using little land but a lot of laborers, tend to locate themselves spatially near each other to benefit from agglomeration effects, particularly through sharing infrastructure, larger and more

diversified labor pools, and larger local markets. As firms expand and hire more laborers, the laborers and their families will choose to live near their firms to cut traveling time and cost. The service sector will expand accordingly in response to this growing non-farming population, causing further expansion of the existing urban centers and the emergence of new urban centers. Since the origin of this type of urban expansion is economically driven, unlike urban centers formed on political, bureaucratic, or military considerations, they represent endogenous urbanization, an important part of endogenous growth. This is the only type of growth that is sustainable in the long-run, because it relies on deepening divisions of labor and specialization, and better ways of sharing public inputs instead of simply relying on increasing inputs. The endogenous urbanization generates agglomeration effects and promotes technical progress, institutional innovation, accumulation and spillover of human capital (Lucas 1988 and 1993; Barro 1990 and 1998; Yang and Ng 1999).

The opposite holds if a nation for some reason acquires new land, causing an improved man-to-land ratio. Population will disperse to newly acquired land, causing the expansion of the land-intensive sector and the contraction of the labor-intensive sector. This implies that existing urban centers will decline accordingly. As the society loses some of the agglomeration effect, part of the endogenous growth will be lost too.

3.3 China's problematic land data

By using geographical endowments and their changes, we also can correct the serious inconsistency in the Chinese historical data regarding cultivated land. For example, it is well established that the Sui dynasty was significantly smaller than the Tang in terms of territory (Tan 1982, Vol. 5), and it was during the Tang that the land in South China

started to be reclaimed. However, according to Liang (1980),¹⁶ the Sui had more cultivated land than the Tang (Table 1). We also know for sure that the territory of the Qing was much greater than that of the Sui (Tan 1982, Vol 5 and Vol. 8). However, according to Table 1, the cultivated land in the late Qing was less than half of that of the Sui.

Table 1
Cultivated Areas

The Common era	Dynasty	Cultivated land (million mu)	Per capita cultivated land (mu)
2	Han	827	13.88
105	Han	732	13.74
589	Sui	1940	
726	Tang	1440	34.78
976	Early Northern Song	295	
1021	Early Northern Song	524	26.33
1066	Middle Northern Song	440	15.12
1083	Later Northern Song	462	18.49
1381	Early Ming	367	6.13
1393	Early Ming	851	14.05
1426	Middle Ming	412	7.94
1502	Middle Ming	623	12.23
1578	Later Ming	701	11.56
1602	Later Ming	744	20.64
1655	Early Qing	388	27.63
1661	Early Qing	527	27.51
1701	Early Qing	599	29.33
1734	Middle Qing	890	32.54
	Later Qing	912	2.41

Source: Liang, 1980.

Data from the Ming dynasty also look suspicious. If the sharp rise in cultivated land during the period 1381 to 1393 can be attributed to the quick recovery from war once

¹⁶ I appreciate Liang's effort to comb through all the historical documents in order to get the data on China's cultivated land, and realize that in response to different tax policies under various dynasties, people could underreport their land to evade land taxes.

order and peace were reestablished in the early Ming, it is totally incomprehensible why the amount of cultivated land would drop sharply in 1426 when the Ming was enjoying peace, order, and prosperity. Using geographical boundary data we can correct the serious distortion in those land data. The reasons are as follows. First, it is easier to verify international boundaries by using cross-national data.¹⁷ Second, the topography of a nation changes at a speed beyond perception. While a piece of land can be left idled, it was almost impossible to destroy that piece in pre-modern times. Once wars are over, people can reclaim the land from nature within a short period of time, as the experience of the early Ming shows. Therefore, we can infer the upper limitation of a nation's total arable land available once we know a nation's geographical boundaries, and then use this knowledge to correct the distortions in the historical data on cultivated land.

3.4 Main hypothesis and the definition of geographical endowments

The central hypothesis of this paper is as follows. *The Needham puzzle can be explained by the differences and changes in geographical endowments that different civilizations faced in the pre-globalized world.*

Geographical endowment in this paper refers to the explicit and implicit geographical constraints, including topography, ecology, climatic conditions (which define the length of hunting and gathering seasons, and later when agriculture developed, the length of growing season), natural endowments (which define the acreage and fertility of arable land, water supply, and important mineral deposits), and locations (accessibility to rivers and oceans, to trade opportunities, and to other major civilization centers for knowledge, information, and technologies).

¹⁷ Just like the trade data, people can use different sources of data to verify the information on a nation's boundaries. In general, data on import and export are much more accurate than GDP, because one can use cross-national data to verify a nation's trade data.

This paper emphasizes the role of geographical factors in economic development and technical progress, but its approach is very different from the traditional geographic determinacy for the following two reasons. First, in this paper geographical factors enter production and consumption through a nation's long-term budget constraints. Second, since geographical conditions of a specific area determine the initial carrying capacity of a land, and in turn the initial size of a population living on that land, population itself is an endogenous variable. As Lin (1995), Diamond (1997), and this paper show, population's size and growth can in turn affect many other factors including technical progress, transportation costs, and communication costs in dealing with neighboring societies. Therefore, while geographical factors cannot be deterministic forces in the formation of culture, institutions, or technologies, because the latter are contingent on many other factors, the geographical factors greatly reduce the range of possible outcomes in these domains. Using Mokyr's term "constrained contingency" ((2002), geographical factors serve exactly as such constraints by restricting the range of potential outcomes available to a society in a specific location.

Based on such a constrained contingency, we can argue that certain combinations of geography, topography, location, and climate are more conducive to the emergence of certain cultures, institutions, attitudes, world outlooks, and behavior. They in turn are more conducive to knowledge accumulation, technological breakthroughs, and economic growth and development.¹⁸

¹⁸ Sea-locked Japan evolved in a relatively more isolated environment than China until it came in contact with the Chinese civilization via the Korean peninsula. In contrast, the continental nature of China's geography exposed it to frequent invasions by the nomadic nations from the north and west, but never from the south, an area populated by agrarian nations. Imagine what would have happened had India and the Southeast Asia been grassland or Gobi desert, but north to China been fertile land with sufficient rainfall and big rivers.

IV. Geographical endowments and the successive rise of ancient civilizations

4.1 Middle East—the key to the first Needham issue

The answer to the first Needham issue, i.e., why China was not a leading nation in technology before 200 AD, is largely geographical. Using the three criteria of civilization (evidences of a writing system; of urban centers; and of a hierarchical social structure), we immediately see that although the prehistory of China can be traced back to very ancient times, based on the dated evidence of the writing system, the Chinese civilization emerged much later than Sumer and Egypt in the Middle East.

According to Diamond (1997) and Cook (2003), the sequencing of the emergence of civilizations is not a pure accident, but due to geographical reasons. The Middle East as a favorable habitat was the first stop for Homo sapiens on their way out of Southeast Africa. It is located in the eastern Mediterranean area, and shares the unique Mediterranean climate, characterized by hot, dry summers and mild, wet winters. The hot but dry season prevents tree seeds from spreading and forming thick forest in this area, and instead allows mostly annual plants to take over the land. The latter tend to have bigger seeds relative to their bodies, thus easily getting the attention of early gatherers. No wonder some of the earliest domesticated crops, such as wheat and barley, originated in this area.

The vast grassland also provides a favorable environment for large but docile herbivores, and explains the origin of some domesticated animals such as horses and goats. The existence of big rivers provided badly needed water for farming to overcome the problem caused by lack of rainfall during growing season. The combined effects provided most

favorable conditions for the first sustained agricultural revolution to take place here during the late Neolithic era, earlier than any other area on Earth.

Once this agricultural revolution took place, most areas of the Middle East could be easily cultivated even with primitive stone tools. In areas where there grew thick forests, large scale land reclamation had to wait until metal tools became available. As cultivated land expanded and carrying capacity grew in the Middle East, population proliferated to a larger size than anywhere else. A larger population accelerated the early emergence of civilization through the positive chain reactions described in Lin (1995), and in more detail in Diamond (1997), and briefly discussed in Section 2.2 above.

The Middle East was not only the first to launch an agricultural revolution, but also the first to enter Bronze Age, about 5000 years ago, at least 1500 years earlier than the Yellow River Valley. The Middle East also entered the Iron Age 3200 years ago, about 700 years earlier than China (Cook 2003 p28).

As in the Middle East, the reasons for China's emergence as an independent civilization are largely geographical too. Northern China, the cradle of the Chinese civilization, had warm, wet summers, and cold, snowy winters in ancient times. The whole plain used to be covered by a thick forest. The agricultural revolution here started rather early, but the local population had to wait until the advent of metal tools before reclaiming land from the dense forest on a large scale. Accordingly, it took much longer time for the population in North China grew large enough to nurture the birth of an early indigenous civilization, as evidenced by the fact that the writing system did not emerge until about 3,500 years ago (Cook 2003), much later than in the Middle East.¹⁹ Compared with the

¹⁹ According to Grove (1997 pp28—31), the earliest civilization emerged in Sumer about 7,000 years ago. According to Cook (2003), it was around 5000 years ago in Sumer. No matter which case is true, the

dates of early civilizations in the Middle East, the Chinese civilization was certainly a later comer.

In terms of technology, the Chinese civilization was also quite backward compared with the contemporary civilizations in the Middle East at this stage. For example, the first pyramid, at 481 feet in height, was built during the reign of Khufu between 2551 BC and 2528 BC. It remained, according to Agnese and Re (2006), the world's tallest structure "until the construction of Eiffel Tower in 1889". Its volume of 95 million cubic feet is composed of around 2.5 million blocks of stone averaging 5,500 pounds, or about 2.5 tons each. What is amazing is that the total difference of the four sides of the pyramid's base is only eight inches, and the deviation of the entrance face from due north is just 0°3' 6" (Agnese and Re 2006, p69). Obviously, about 4500 years ago, the ancient Egyptians already had a very good command of engineering, geometry, astronomy, measurement, moving and lifting equipment, and the skills and tools to cut and chisel large stones. The successful completion of the Khufu and other pyramids in the Giza area, and later numerous huge temples in Luxor and other areas along the Nile, was the best testimony of the mobilizing and organizing capacity of the Egyptian civilization. At the time the Egyptians managed to accomplish all these engineering feats, China was just emerging from barbarism. It is apparent that China could not have been a leading nation throughout this long period.

4.2 Unique Greek geography and the second Needham issue

The answer to the second Needham issue, i.e., why modern science only emerged from European culture, can be provided largely through geography as well. The spontaneous

Sumerian writing system emerged at least 1000 years earlier than in China, where the early writing system, exemplified mostly by inscribed oracle bones left from the later Shang dynasty, emerged about 3500 years ago.

curiosity about Nature and logical reasoning, criticisms of conventional wisdom, and challenges to norms and authorities, could happen among all cultures,²⁰ but most cultures would not provide the right environment to encourage such critical thinking and rationality. Ancient Greece was an exception. As Huff (1993) points out, "...the foundations of modern science, both cultural and institutional, are to be found precisely in those areas outside of science where men speculate about the nature of the cosmos, in its deepest and most mystical sense, and where the human imagination forges the institutions that allow individuals to perpetually enjoy *neutral space free* from the incursions of political and religious censors."

Although it shared the same Mediterranean climate as the nearby Middle East, Greece had a very different topography. Most conspicuously, Greece did not have vast plains and big rivers, as the civilizations in Middle East did, to support a large agrarian population that relied on it in turn to build a large kingdom or an empire.

The Greek civilization was located on the Balkan Peninsula, known for its deep mountainous inland, and the small and scattered plains along its shores. These small plains were ideal for the emergence of city-states (Cook 2003). The fact that none of them had large plain hinterlands to support large populations precluded any city-state from rising quickly to dominate other cities. The unique Mediterranean climate combined with small and scattered plains was not particularly conducive to farming, especially not for grain, a typical land-intensive product.

However, the Greek geography has its own merits. First, the location of Greece was strategic for the exchange of goods and knowledge. The distance between Greece and

²⁰ Approximately at the same time China saw the rise of the Mohist school. This school was interested in logic and scientific questions. However, this school, together with many others, was soon suppressed by the first emperor of the Qin dynasty and was never encouraged by subsequent emperors (Cook 2003 p187).

the nearby civilizations in the Middle East, either via continental or maritime routes, was quite short compared with other parts of Europe. It was really a blessing to the Greeks to live next to these great civilizations. The timing was even better. While the Greeks were rising out of obscurity, the nearby civilizations were already at the apex of their maturity after 2000-3000 years' growth.²¹ Not only could they provide grain to the Greeks through trade, but also various intellectual stimuli. Second, since most Greek city-states were not self-sufficient in grain, and had to export wine, olive oil, and pottery among other commodities to trade for wheat and other food,²² the Greek economy, including its farming sector, was to a significant extent connected with domestic and foreign markets instead of being locally oriented. Third, even with food imports, the city-states with their small plains could not accommodate their own population growth. Consequently, overseas commercial activities, adventures and colonization became necessities in the Ancient Greek lives.

Combining these facts, we can see that because of the commercial role of Greek cities around the Mediterranean (Bairoch 1988), there was a built-in incentive among Greeks to be outward-looking, to seek information, and to be curious about the outside world in order to secure foreign markets for trade and overseas territory for emigration.

Information and knowledge naturally followed the imports to flow in from the nearby civilization centers. In short, there was not only a built-in demand for, but also a natural supply of, information and knowledge. By the means of international trade, new ideas,

²¹ The influences from outside included the Minoan civilization in Crete that was deeply influenced by Egyptian civilization, the Persian civilization in Asia Minor that inherited much from the Sumerian, Assyrian, and Babylonian civilizations among others, and the Phoenician achievements in the fields of sailing, colonizing, and spelling system, to name a few.

²² According to Bairoch's estimation, "...Greece probably had to import a quantity of grain sufficient to support some 20-40% of its urban population, if not more." (1988 p77)

knowledge, and technology flowed in from the nearby civilization centers. Unlike China, which, for a long time, was a lonely forerunner in her isolated environment, the Greeks had plural reference systems provided by the Minoans, Egyptians, Babylonians, Persians, Assyrians, and Phoenicians among others. Many Greek scholars traveled extensively to these civilization centers.²³ Such travel experiences and commercial contacts greatly expanded the world outlook of Greeks. Fourth, the Aegean and the Mediterranean played “a mediating and unifying role” (Bairoch 1988 p71) among surrounding civilizations, while also forming natural barriers, and making it much harder for foreign powers such as the Persian Empire to invade and conquer. This permitted the Greeks a more independent path of evolution. This constituted a sharp contrast with the doomed Phoenicians whose cities were not separated by seas from the nearby empires and were unable to escape being conquered eventually. Fifth, a peninsula with only one way out, very similar to an island, tends to screen out intruders, resulting in ethnic homogeneity (Cook 2003). This explains why the competing Greek city-states shared the same language, culture, and tradition.

However, these five reasons can only explain why Greeks rose from obscurity to the forefront of the world arena in a relatively short period of time. The Greek catching-up, while impressive, was by no means unique. Throughout history, numerous nations have risen from obscurity in relatively short periods of time. Those who happened to live next to inspiring civilizations could have very steep learning curves, especially when they were motivated to imitate. China itself witnessed the fast catching-up of numerous nomadic nations living along its northern border. Various nomadic tribes learned almost

²³ See, for example, what Herodotus wrote in his famous *History* about his own travel experiences in Egypt and other Middle Eastern countries.

every technical trick from China in just several hundred years before many of them defeated China on the battlefield.

However, usually the growth in barbarians' knowledge and technology leveled off after catching up. What really made the Greek experience a miraculous exception lies first in the fact that during the classical period, the ancient Greeks leaped forward, leaving other civilizations far behind in terms of technology and scientific thinking, and second, in the fact that the Greeks succeeded in achieving this feat with a relatively small population size,²⁴ a departure from all the other ancient civilizations. What the Greeks achieved cannot be explained by Lin's hypothesis, but can be by geographical hypothesis of this paper. The unique geography of Greece gave rise to its unique social institutions and organizations. The latter in turn gave the Greeks a big edge over all the other civilizations in acquiring unconventional sources of growth.

First, Athens and some other Greek city-states adopted democracy. Consequently, truths could be sought openly without the fear of political persecution by kings or priests who often viewed truths as their monopoly. Second, the Greeks benefited from the agglomeration effect that arose from its many competing urban centers. Third, the inherent urge to trade with and colonize other areas around the Mediterranean encouraged not only scholars, but the public at large to be curious about foreign markets, foreign cultures, and foreign ideas in order to get information relevant to commercial interests and colonial enterprises. Fourth, the Greeks must have benefited from gains from trade.

Such gains, which did not dawn on any nation until Ricardo explained them in his theory

²⁴According to Bairoch (1988 p76), the total population of Greece around 500 BC was about two millions. On average, a typical city-state had a small population of no more than 20, 000. Among the few that had a larger urban center, Athens had the largest population. The urbanization levels of different city-states varied in the range of 15-30%. Obvious, the total population of ancient Greece was easily dwarfed by other agrarian civilizations.

of comparative advantage, are part of the reason why Athens and other city-states with small population and barren land could have completed so many huge public works during the short classical period (510-331 BC). Fifth, the adoption of the spelling system that the Greeks learned from the neighboring Phoenicians must have greatly eased the difficulties in reading and writing, and hence promoted education among Greeks. The human capital of an average Greek citizen must have been higher than his or her counterpart in other civilizations where hieroglyphs, pictographs, or cuneiforms were in use. In the latter case, only a very small upper class, mostly noblemen and priests, could have the leisure and resources to learn and master them. The vast majority was left illiterate and ignorant.

In summary, when the writing system and knowledge were not monopolized by a small upper class, when political institutions were based on democracy, when urban centers attract people of all walks to meet, to deal, to debate, and to participate in public policy decisions, when an economy was market driven and trade oriented, and when competitive trade and commercial activities demanded fact-based information and accurate accounting, then errors, mistakes, misinformation, superstition, blind obedience, and unchallenged and unaccountable authorities would more likely yield to fearless searches for truth, logic and fact-based reasoning. Such an environment would more likely provide fertile soil for the rise of rationality, scientific thinking, and scientific methodology.

Some of the Greek philosophers such as Aristotle, Euclid, Archimedes, and Herophilus should be referred to as scientists today, because they already knew how to use deductive techniques or fact-based experiments to test refutable proposition in their reasoning and

experiments. Logic-based and facts-based critical thinking was the very basis of scientific methodology. In this sense, it is indeed true that the embryo of modern science arose first in ancient Greek philosophy (Yang 2003 p3). This new way of thinking enabled Greece to overcome its small population size to deepen and broaden their epistemic base, which in turn helped them to accelerate scientific and technological progress.

V. The Elvin hypothesis and the technological explosion in the Song

5.1 The third Needham issue

The answer to the third Needham issue, i.e., why China became a leading nation only in the field of practical technology during the period from the second to sixteenth century AD, is apparent in light of Lin's hypothesis. According to Lin (1995), when invention is experience-based, population size is the main determinant of the frequency of new inventions.

The North China Plain is vast and one of the best endowed in the whole Eurasian landmass as long as farming is concerned. Once metal, especially iron tools became available, the North China Plain could support a far larger population than the Fertile Crescent, the Nile valley, or Europe.²⁵ Iron tools became widely used in China during the Warring States period (475-221 BC). By the beginning of the Common Era, according to Maddison (2001), China already became the most populous nation in the world.²⁶ In Figure 2, we see that China's population has been larger than that of Europe since at least 400 B.C. As the unconventional sources of growth in the Greek world gradually disappeared after the Macedonians and then the Romans rose to hegemony and placed the

²⁵ Compared with copper or bronze tools, iron tools are much more efficient. China entered the Iron Age during the Spring and Fall and Warring States period. Europe entered the Iron Age earlier than China.

²⁶ According to Maddison (2001), China sometimes yielded this title to India.

Greek city-states under their control, China's demographic edge over other civilizations started to loom large and eventually to surface.

However, this surfacing was gradual, because the Greek influence did not disappear overnight. It was kept in a transplanted environment, i.e., at the Library of Alexandria for several hundred years without its original fertile soil.²⁷ After the destruction of the library, the memory of Greek wisdom and knowledge was kept by a small circle of monks and intellectuals in Constantinople and in some Arab cities, but mostly faded away among the population at large, especially in areas once ruled by the Western Roman Empire. People returned to the original mode of invention—that is, experience-based instead of experiment-based. As nations resumed conventional growth, population size stood out as the determinant of invention once again. China, by now the most populous nation, moved to the forefront for the first time in the second century A.D. However, as Needham points out, China never developed scientific thinking, and its inventions were all applications of knowledge about Nature to production or living.

5.2 Elvin's hypothesis, the H-O theory and the Song Miracle

According to Elvin, the rising man-to-land ratio in late imperial China led to lower productivity and surplus population, resulting in lower labor cost relative to the cost of capital goods, reduced demand for labor-saving technology, and less savings available to finance new inventions (Figure 2). This is a powerful hypothesis and still influential among Sinologists.

However, there are two problems with Elvin's hypothesis. First is factual. He assumes that land area was constant (1973 p313). In reality, China experienced significant

²⁷ By fertile soil, I mean democratically organized city states that had an active urban life, trade and a commercially oriented economy with extensive international ties.

fluctuations in its boundaries, and consequently in the availability of arable land. Elvin also assumes that China's population was increasing linearly over time. In reality, China experienced severe losses of population at the beginning of almost every dynasty except for the Song (Figure 1). Combining these two facts, we can see that the man-to-land ratio, instead of rising monotonically, often improved before worsening again (I will discuss this point in detail later).

A second problem in Elvin's hypothesis is logical. His hypothesis cannot explain why it was mainly during the Song dynasty that China made the most profound technical advances. These advances were of a labor saving nature, but were put into mass use soon after being invented. This occurred generally at a time when China's population pressure peaked as a result of losing large amount of arable land to invading nomads. It was exactly during this period when China experienced an explosion of new inventions and innovations (Fairbank and Goldman 2006).

Let's look more closely. First, China's most important inventions indeed took place during this period (Elvin 1973; Landes 1998; Qi 1999). Second, China reached its highest urbanization level, and the functions of urban centers underwent profound changes during this period. Third, it was during Song that the Chinese government relaxed its monopoly and allowed the private sector to participate in foreign trade by transforming the money-losing tribute system to a commercially sustainable trade system. Fourth, as a result of these social and economic changes, for the first and last time before the modern era China collected more tax and tariff revenues from commerce and trade than from its land (Fairbank and Goldman 2006). These socio-economic changes, representing a major breakaway from China's self-sufficient agrarian past, cannot be

explained by Elvin and Lin, but can be explained by the H-O theory and the Rybczynski Theorem. Let's examine the facts in detail.

5.3 Changes in Territory and population during the Song

Compared with the Tang (618-907 AD), China during the Song (960-1279 AD)²⁸ lost the whole Northwest (Central Asia) and Northeast (Manchuria) right at its birth. The northern boundaries were pushed to the south of the Great Wall. Part of the North China Plain was lost first to the Liao (916-1125), and then to the Jin (1115-1234), two states established by nomads. With the Great Wall controlled by the northern nomadic neighbors, the whole north of China was exposed to frequent harassment, plunders, and invasions first by the Liao, and the Jin, then by the Mongolians. The ensuing uncertainty and vulnerability forced many Chinese to migrate to the South from the North. China eventually lost the whole North China Plain to the Jin in 1127 AD and retreated to the south of the Huai River.

As the South attracted more and more migrants from the North, population pressure built up in the South. Unfortunately, the landscape of the South was very different from the North. There were plains in the South, but they were much smaller than the North China Plain, and mainly located along the middle and lower Yangtze and its tributaries, separated by hills and mountains. Many of them were swamps because of the frequent floods from the Yangtze or from the big lakes such as Tai, Boyang, and Dongting. Unlike the North China Plain, therefore, these plains were not naturally good for living and farming before first being drained. It took labor, capital, and a long period of

²⁸ From 907 – 960 AD, the so-called Five Dynasties period, was one of the many times when China split into many small states. But this was the only period when its population was growing continuously. During other periods when China dissolved into many small states, or when an old dynasty's was replaced by a new one, population as a rule plunged significantly. Figure 2 verifies this fact.

gestation before land could be reclaimed from swamps or hilly slopes. The combined effects of the influx of migrants from the North and the lack of ready-for-use arable land in the South resulted in rising population pressure throughout the Song.

5.4 Urban expansion and functional transformation

In response to the losses of large amounts of arable land during the Song, as the H-O theory and Rybczynski Theorem predict, China’s labor-intensive sector expanded, resulting in the concentration of growing urban populations. The service sector rose in response to the needs of the growing urban population (Table 1). It would take about another 800 years before China reached the same level of urbanization again (in the early 1980s).

Table 1
Urbanization level in China’s History

The Warring states (300 BC)	15.90%
Western Han Dynasty (2 AD)	17.50%
Tang (745)	20.80%
The Southern Song Dynasty (around 1200)	22.00%
Qing (1820)	6.90%
Qing (1893)	7.70%
1949	10.60%
1957	15.40%

Source: Chao, 1995, p76.

Kaifeng (Bianjing) and Hangzhou (Lin’an), as the capitals of the Northern and Southern Song respectively, were the largest cities in the contemporary world, boasting more than one million people each. In addition to these two big cities, there were many other large cities, according to Gernet (1962) and Shiba (1975), such as Suzhou, Nanjing, Ningbo, and Quanzhou. They were all internationally renowned manufacturing centers or trade

ports with large populations. According to C. Huang (2003), new cities specializing in ceramic production were also emerging along the Fujian and Zhejiang coastal areas during the Song in response to the growing demand for porcelain from overseas, although they were deserted later during the Ming and Qing.

China not only saw the rise of big cities and the emergence of new ones during the Song, but also saw the profound transformation of their functions. During the Tang dynasty and earlier, cities mainly played a political role as national or provincial centers, or as military strongholds. Commercial activities in cities were subject to political or military restrictions. According to Yang (2003, pp 237-238), city authorities before the Song imposed very restrictive rules on business activities. For example, each city designated only a few walled marketplaces for commercial use. Government guards patrolled these places regularly and locked up the gates after the officially designated business hours. There was little life in cities after dark. The city gates were all closed. One needed special permits to move around or to pass through any of the city gates. Those who walked around without permits were subject to penalty or arrest. Beside the officially designated marketplaces, no other places within a city could be used for commercial activities. Houses could only have windows and doors facing back alleys or small lanes. Along the thoroughfares the city authorities did not allow any windows or doors to be installed so no one could have a peep at the movement of officials or garrisons. Even all the lanes and alleys had their own gates, and were locked up after dark. The curfews imposed on cities and the regulations governing the marketplaces, while maximizing the security of cities as political centers or military strongholds, prevented economic and commercial activities from thriving.

During the Song, curfews and regulations of this type were lifted. Commercial activities were allowed in most parts of a city at any time. Residents were allowed to open front doors and windows into main streets and thoroughfares, or convert their houses into shops and stores. The government encouraged the formation of various guilds (Chen and Qiao 1998) because these guilds helped facilitate the collection of commercial taxes. These guilds, however, also played a more positive role in protecting free competition among member firms.

5.5 From money-losing tribute system to mutually beneficial trade system

As Fairbank and Goldman (2006) point out, during the Han and Tang dynasties, China replaced its trade system with the tribute system.²⁹ However, this tribute system underwent profound changes during the Song. Defeated and humiliated frequently by Liao, Jin, and later by the Mongolians, the Chinese emperors during the Song had few illusions that they were superior to their neighbors, a belief that the Chinese officials and people typically had before and after the Song. Landes (2006) has emphasized this belief as one possible explanation of China's failure to learn from foreigners. During the Song period, the fact that China had to pay heavy tributes to northern powers to buy short-lived peace made the Song emperors more pragmatic in their attitudes toward trade, according to C. Huang (2003). According to him, China abolished many of the practices typically observed under the tribute system. For example, in order to reduce financial losses, it discouraged its neighboring nations from sending their envoys to China, but encouraged foreign merchants to come in order to raise more tariff revenues.

²⁹ The tribute system actually aimed at political loyalty and the respect China sought from its neighbors. In return, China showered them lavish gifts such as silk, porcelain, and other highly regarded handicrafts. These exchanges often became heavy financial burdens for China.

The government also relaxed its monopoly on international trade, viewing tariff revenues as an important source of income. It allowed the private sector to trade directly with foreign merchants in China or abroad, a policy that China abandoned in the Ming and Qing. In order to share the possible risks inherent to overseas trade, people tried new commercial and financial practices (C. Huang 2003). The lucrative nature of foreign trade attracted people of all walks, from merchants to ordinary people, from officials to generals, even nuns and monks. China had never seen its trade ties so extended as during the Song. Foreign merchants from Korea, Japan, Southeast Asia, India, Arabia, and East Africa came to China via maritime routes. Copper coins, silk, tea, porcelain, and many other labor-intensive manufactured products, and knowledge-intensive products such as books and paintings were among the most sought-after Chinese exports. In return, China imported grain, cattle, timber, minerals, spices and other land-intensive products.

Chinese ships, known for their size and weight, and guided for the first time in the world history by magnetic compasses, regularly visited ports in Southeast Asian and the Indian Ocean (C. Huang 2003). It was also during the Song that China became the first nation in the world to adopt paper money and put it into wide circulation, a breakthrough in monetization and commercialization. This invention reflected both the growing demand for money, and willingness to base business on trust and credit.

5.6 Song was searching for an unconventional path to the future

The combined effect of the rising urbanization level, the changing urban functions, the wider division of labor, prosperous commerce, the wider use of money including paper money, and the highly visible participation of the private sector in foreign trade, provided a more favorable environment for new inventions during the Song. An increasingly open

economy enabled China to organize its production in a manner responsive to worldwide divisions of labor and specialization (within the world known to China). Not accidentally, Fairbank and Goldman (2006) point out that China collected for the first time in its long history more tax and tariff revenues from commerce and trade than from its land during the Song. The extensive trade relations with foreign nations imply that there were relatively free exchanges of ideas and information between China and its trading partners. According to C. Huang (2003) many Arab merchants actually chose to live in China's big cities such as Quanzhou. Given the fact that during this period Arabs were keepers of the ancient Greek legacy and were leading the world in many fields (Huff 1993), these exchanges with Arabs must have provided a favorable and stimulating environment in China for new inventions and innovations, and more importantly, for their rapid applications, a rare phenomenon in China after the Song. As Landes (2006) points out, most of time in China "the history of advances, ..., is one of points of light, separated in space and time, unlinked by replication and testing, obfuscated by metaphor and pseudo-profundity, limited in diffusion... in effect, a succession of ephemera." The Song dynasty was an obvious exception.

VI Territory expansion and technological stagnation

6.1 The fourth Needham issue

Now let's look at the possible answer to the fourth Needham issue as to why China lost its technological lead and then, after the 16th century, became a relatively backward nation even in practical techniques. A simple answer to this issue is: While Western Europe resumed the path once taken by the ancient Greeks characterized by urbanization,

commerce, trade, and overseas colonization, China retreated back to its agrarian past from the track attained during the Song. This divergence not only explains why Europe advanced so fast, but also explains why China degenerated into a backward nation so dramatically.

To see why China would prefer to go back to its agrarian past, let's take a look at the man-to-land ratio after the Song. The subsequent dynasties after the Song are the Yuan (1271-1368), Ming (1368-1644), and Qing (1644-1911). Each of the three dynasties experienced, at least at their early periods, population declines relative to their territory. These trends were often the opposite of the Song's experience.³⁰ Using geographical boundary data instead of unreliable household data on cultivated land (see section 2.3), China's man-to-land ratio actually improved throughout the whole Yuan period, most of the Ming period, and from the early to middle Qing for the following reasons.

First, throughout the whole Yuan, population continued to decline while China's territory became much larger than that of the Song (Tan 1982, Vol. 7). Second, during the early Ming, China saw a declining population until 1400. Its total population did not surpass the peak of the Song until around 1500 (Figure 2). It is true that the Ming's total territory was smaller than that of the Yuan, but much greater than that of the Song. What the Ming lost were Mongolia and Xinjiang (Tan 1982, Vol. 7), which were never China's main agrarian areas. Compared with the Song, the Ming's territory was much greater, as the country regained part of Manchuria and the whole Southwest. Both had favorable climates for agriculture. By pushing the northern border back to the Great Wall and beyond, the Ming also secured the North China Plain, the most important agrarian area in

³⁰ Population in the middle Ming experienced further growth after recovering to the peak of the Song. The Qing repeated the same pattern, although it grew to a much larger population in the 18th century. However, throughout the Yuan, the population never reversed its declining trend.

China since ancient times. Third, and most importantly, after the middle Ming, land-saving and water-saving crops such as peanuts, potatoes, sweet potatoes, corn, and cotton, were introduced into China and expanded rapidly. This significantly enhanced the carrying capacity of the hilly South and mountainous Southwest, making them the new destinations for large-scale migration. Because of the relatively short growing period, these crops were also suitable for the fertile but cold Manchuria plain.

Combining all these factors, it is safe to say that compared with the Song, the man-to-land ratio during the first half of the Ming (1368 to 1500) was actually improved. Even after then, this ratio did not deteriorate immediately for the following reasons. First, the Ming had a much larger territory than the Song, but its population was about the same as the Song by 1500. Second, given the availability of land and water-saving crops in the late Ming, the man-to-land ratio would not become much worse until 1600 when its population grew to be much larger than that of the Song.

The Qing had a similar pattern with regard to the changes in its man-to-land ratio. In Figure 2, we can see that the population declined at the beginning of the Qing, and it did not recover to the Ming's peak of 160 million until after 1700. Meanwhile, during the Qing dynasty, China's territory was further expanded from what it had been under the Ming's reign. It gained the whole of Mongolia, secured control over Xinjiang, Tibet and its adjacent areas, acquired Taiwan, and expanded and secured its control over the whole of Manchuria. Except for Manchuria, some parts of Xinjiang, and Taiwan, it is true that the other newly acquired or secured territories were not good for China's traditional staple crops of rice and wheat. But when potatoes, sweet potatoes, peanuts, corn, and cotton became part of farmers' choices, these newly acquired or secured territories

actually accommodated much of the population who migrated in large-scale from eastern and central China.

This is exactly what the H-O model and the Rybczynski theorem predict. According to them, the acquisition of new territory will lead to the expansion of the land-intensive sector at the expense of the labor-intensive sector. In light of these theories, we should expect to see the spread of population from the center to more peripheral areas in pursuit of arable land. Urbanization levels would decline as a result of the contraction of the labor-intensive sector. During the Ming and Qing, as large amounts of population moved to the vast and newly secured inland and deep mountains at a time when transportation and communication infrastructures were backward, the economy became more inward looking and self-sufficient. The importance of domestic commerce and foreign trade declined. All these socio-economic changes led to a decline in the nationwide divisions of labor, reduced specialization, reduced levels of urbanization, reduced agglomeration effects, and stagnant technology. Let's look at the empirical data in detail.

6.2 Large-scale migration to the new frontier

From the Yuan on, China saw its population increasingly dispersed, usually from the center to the Southwest, Northwest and Northeast. The linguistic evidence supports this statement. For example, China's Southwest covers a huge geographical area known for high mountains and deep valleys. As the severe differentiation of dialects in China's hilly Southeast³¹ shows, language in the mountainous terrain of China's Southwest

³¹ In sharp contrast to China's Southwest, in China's Southeast there are many highly differentiated dialects. The local dialects in Jiangxi, Zhejiang, Fujian, Guangdong, Jiangsu, and Hunan are very hard, if not completely impossible, to understand for Mandarin-speakers today. Although the accent of the local dialects was close to that of China's central area as late as during the Tang, the mountains, valleys, long distances, and long intervals of separation from their mother tongue made these dialects very different from each other, let alone Mandarin, in their accents.

should have also highly differentiated. Surprisingly, the dialects prevailing in this area today are very close to Mandarin and can be understood by Mandarin-speakers. Since Mandarin as an accent was formed during the Yuan, and has become the prevailing accent in the North China Plain since then, one can infer that the majority of the local people in the Southwest must be the descendents of those who came from China's Mandarin-speaking areas during or after the short-lived Yuan period.

Beside the difficulties in transportation and communication caused by deep mountains and valleys, long distance usually also plays a significant role in differentiating dialects from their mother tongue and from each other. However, the accents of the dialects in Northwest and Northeast are very similar to that of Mandarin despite the remote distance. This fact suggests that the local population in China's Northwest and Northeast were descendents of more recent migrants from Mandarin-speaking areas.

Historical documents show that during the Yuan, Ming, and Qing, there was large-scale migration. First, in response to the depletion of the population in the North China Plain by wars and nomadic invasions, the early Ming emperors forced the populations of some big cities in the lower Yangtze (the most developed area in contemporary China) to move to the North (Chen and Qiao 1998 pp24-25). As population pressure built up in China's central area, more people were driven into more hilly or mountainous areas in Southern Anhui, Western Hunan, Guizhou, Guangxi, Yuannan, and Sichuan during the Ming. During the Qing, as the population pressure built up again in central China, many moved to the Northwest (the Central Asian part of China) and the Northeast (Manchuria).

6.3 Declined urbanization level

Table 1 shows that China's urbanization level, from the peak of 22% during the Song fell to as low as 9% in the late Qing.³² China also saw the relative stagnation of its large urban centers compared with Europe. For example, although China was known as the home of some of the largest cities in the world during the Song, such as Kaifeng, Hangzhou (Lin'an), and Quanzhou,³³ between the period 1500-1900, not even one of the ten largest cities in the world was located in China (Table 3). This is particularly odd given that China was far more populous not only compared with Italy, France, and England that possessed such big cities throughout this period, but also compared with its own earlier period.

No wonder that Fairbank and Goldman (2006, p.172) feel "strange that after the Song cities of Kaifeng and Hangzhou were established, no great cities of over a million emerge in China until the nineteenth century." If big cities symbolize a higher level of division of labor and specialization, the stagnation in the growth of big cities certainly indicates stagnation in the deepening of division of labor and specialization of the Chinese society. As population dispersed to the vast inland (section 6.2 above), the household industries also spread from coastal areas to the vast, formerly underdeveloped inland to overcome the increasing transportation and communication costs.

³² Elvin (1973), Skinner (1977), and Bairoch (1988) also notice the reverse in China's urbanization level since the Song, although their figures are much lower for both the Song and the subsequent periods. According to Bairoch (1988 pp353), China's urbanization level peaked in the 12th century when "10-13% of the population of China lived in cities with populations of more than 5,000, making a level of urbanization 1-2 points higher than that in Europe (except Russia)." However, in the period 1500-1850, China's urbanization level declined to as low as 4.1-4.6% (Skinner 1977), or 6.0-7.5% (Bairoch 1988 p357). The reason, according to Bairoch, is that the growth rate of total population was much higher than that of urban population.

³³ Bairoch quotes a great Arab traveler and writer as saying that Quanzhou during the 13th century to 14th century with a population of 500,000 was the largest port in the world. However, according to Bairoch, its population shrank gradually to an extent that it was "practically vanishing by the mid-nineteenth century." (1988 p354)

Table 3

The World's 10 largest cities from 1500-1900

1500	1700	Around 1900
Paris	London	London
Naples	Paris	New York
Venice	Lisbon	Paris
Lyon	Amsterdam	Berlin
Granada	Rome	Chicago
Seville	Madrid	Philadelphia
Milan	Naples	Tokyo
Lisbon	Venice	Vienna
London	Milan	St. Petersburg
Antwerp	Palermo	Manchester

Source: Lo and Yeung 1998. Originally the table is from Chase-Dunn, quoted in King (1990).

In response to the inward movement of population, and the “ruralization” (Chao 1986) or “familization” (Phillp Huang 1991) of handicraft industries, China saw the emergence of numerous small towns in its vast inland to cater to the needs of the localized marketing, production and regional interactions (Skinner 1977).

6.4 Zheng He's voyages and the closed-door policy

It is well established that throughout most periods of the Ming and Qing, China followed a closed-door policy (Fairbank and Goldman 2006) with two exceptions. The first was during the period 1405-1433 when Zheng He, with support from Emperor Yongle, mounted seven naval expeditions to Southeast Asia, South Asia, the Middle East, and East Africa. The second exception was during the late Qing when China was forced to open five seaports to foreign trade in 1842 after being defeated in the first Opium War. In between these two historical events, China only opened its doors briefly several times. Throughout most of the period from the early Ming to the late Qing China only allowed

foreign merchants to visit Guangzhou as a special favor so that they could purchase what they needed. They were not permitted to live in Guangzhou permanently, let alone travel around or reside outside Guangzhou. Because foreign merchants were confined to the small quarters of Guangzhou, a city located in the southern tip of China, the vast majority of Chinese were never exposed to new ideas or new products from the West except for the drug opium, which was smuggled into China in large quantity in the late Qing when Westerners failed to find anything else to sell to China despite its huge trade surplus (denominated mainly in silver).

Zheng's grandiose voyages were remembered mostly for the large number of and the huge size of his boats, the massive size of his entourage, the lavish way in which he showered gifts on various local authorities that he met during his voyages, the maritime distance that his fleet covered, and the historical fact that China reached East Africa ahead of Europe. While it is truly a remarkable achievement by China to have launched these voyages, they left almost no imprint on China's economic development, financial and trade institutions, geographical or anthropological discoveries, or philosophical outlook. Not motivated by commercial incentives or scientific curiosity, Zheng, in sharp contrast to the Song's merchants and the later European adventurers, did not find any worthwhile trade opportunities in this vast area except for some exotic birds and animals. Politically, Zheng accomplished a lot in restoring the reputation of the Celestial Empire which had been stained by the "barbarian Mongolians" during the Yuan, and in reviving the tribute system. However, geographically and economically, Zheng accomplished little, not even finding any land or a maritime route unknown to the Arabs or Indians. Ranking officials at the imperial court sharply criticized his voyages as a waste of the

nation's treasury. Mainly for this reason, China not only stopped sending any more fleets abroad after Emperor Yongle passed away, but also burned all the blueprints of the ships and the maritime maps used by Zheng. China also prohibited non-official trade with foreign nations, and put official trade once again under the yoke of the tribute system as in the Han and Tang, an unfortunate setback from the path that the Song's China was taking. The question is, how could China do so without triggering shortages of food or even causing famine? The answer lies in the fact that, different from the Song's China, China in the Ming and Qing had greatly expanded land.

By the late Qing population pressure was rising again and there is evidence that China was looking for a way out of the agrarian trap. But it was already too late. In the period after the 16th century, Western Europe resumed the path of overseas trade and commerce that the ancient Greeks once explored but stopped. During this period in China, however, after having expanded its continental territory and improved its man-to-land ratio, the nation was nostalgically and happily returning to the old and familiar agrarian path.

6.5 The Rediscovery of the Greek Wisdom and the Renaissance

Let's look at what pushed Europe ahead when China was induced to return to its agrarian past. Commerce and trade oriented cities re-emerged in Italy after the 14th century and gradually spread to the Atlantic coast (R. Huang 1999). The rise of these largely autonomous cities provided a very favorable environment for merchants and scholars to play an active role in city life as had happened in the ancient Greek city-states. Residents of these cities had a built-in curiosity about knowledge and technology because they needed them to conquer the unknown domains and thereby expand their commercial interests.

There is a big difference in the heritage of knowledge between China and Western Europe. The latter had access to the wisdom of the Greeks at a critical moment as it emerged from the Dark Ages, craning for new knowledge. Although the ancient Greek tradition was largely lost in Western Europe by then, Arab and Byzantine scholars had kept it alive. While Western Europeans learned about this tradition indirectly from Arabs (Huff 1993), they benefited most directly from the arrival of the Byzantine monks and refugees. The decline of the Byzantine Empire and its eventual fall as the Ottoman Empire rose to domination led to an exodus of Greco-Roman scholars to the West via Italy. They brought with them manuscripts and knowledge of the classical Greek and Roman civilizations (James and Thorpe 1994 p. xv). Therefore, the fall of Constantinople was a blessing in disguise in a sense, because it actually provided West Europeans with badly needed ancient Greek wisdom and a different world outlook that fueled to a great extent the Renaissance and the scientific revolution.

These two events led Western Europe to switch its mode of invention from the conventional experience-based to the unconventional experiment-based during the 16th century. This switch in the mode of invention would have been much harder, and taken much longer, had the Europeans not been enlightened by the rediscovered Greek scientific thinking in a timely way. The essence of this thinking was as follows. One should propose hypotheses or theories first before examining them by logic (reasoning), facts, or testing them through controlled experiments to exclude those that are falsifiable. Such thinking led to a scientific revolution, which in turn made the Industrial Revolution sustainable. China did not have this crucially important Greek legacy. Therefore, China was only good at applying practical knowledge about nature to human welfare, as

Needham notes. While Europe learned to apply the Greek scientific method as the basis for its mode of invention, China continued to rely on experience-based modes of invention with a “narrow epistemic base” (in Mokyr’s words). Little wonder that China was destined to lose its long-held lead in technologies, once the importance of population subsided.

VII. Concluding Remarks

As China is poised to become the next economic superpower, interest in the Needham puzzle has been revived. China’s past experience indeed looks dazzling and puzzling at the same time. Rising from obscurity to become the world leader in technology in the second century AD, it held this title for the next 14 centuries. China then slipped into the lamentable status of one of the poorest nations in the world in the following few centuries.

While scholars have reached a consensus on the above facts in general,³⁴ they turn to different hypotheses to explain the underlying causes. Among those frequently cited, many blame China’s slippage on its conservative and introverted culture and traditional values (as reflected in Confucianism), xenophobic attitudes to non-Chinese things, repressive bureaucracy and autocracy, mind-binding civil service examinations, lack of diffusing and supporting institutions, imperialism, or the worsening man-to-land ratio. All of them have various degrees of explanatory power, but except for the last two, all of them are endogenous and shaped by some underlying variables. To avoid tautology, we should try not to use these endogenous variables. For example, Confucianism was often

³⁴ Even those who are not ready to accept that China was the leading nation in technology from the second to the sixteenth century, do accept that China was at least one of the leaders during this long period.

cited in the past as a negative factor in causing East Asia's backwardness; but now it is often cited as a positive factor in cultivating work ethics and respect for authorities that led to East Asian Miracle. Such tautology greatly weakens the explanatory power of culture as a convincing variable. The case of the Song dynasty shows that the Chinese were willing and able to change their values, attitude, and behavior when some fundamental variables such as the geographical factors changed.

The only two hypotheses listed above that could be viewed as exogenous or quasi-exogenous are Western imperialism and the worsening man-to-land ratio. To be fair, Western nations did not exert major impacts on China until 1842 when China was forced to open up in the wake of the first Opium War. By then China had long lost its technological lead. Elvin's hypothesis of worsening man-to-land ratio cannot explain why it was exactly during the Song dynasty when the man-to-land ratio was sharply worsened, China achieved most impressive technological advances. Elvin's hypothesis also cannot explain why China failed to achieve major technical progress during the period from the early Ming to the middle Qing when its territory greatly expanded, land-saving and water-saving crops such as corn and potatoes became available, but population was yet to explode.

Lin's hypothesis is very insightful, but cannot answer the following remaining issues. First is the chicken and egg problem. If it is the population size that led to relatively advanced technology, then why was China able to support such a large population from very early on before acquiring such technology? Second, why did the Greek civilization reach a very high level of technology and knowledge with a much smaller population? Third, why did Europe succeed in finding the new invention mode in the 16th century

while China failed? Fourth, when China's population size became comparable or even larger after the mid-Ming relative to that of the Song, why did China become so quiet in invention and innovation compared to the Song?

Based on the implications of the H-O model and the Rybczynski theorem, this paper uses geographical endowments and their changes as its main explanatory variables, because, as Mokyr (1999) points out, "by and large geography is truly exogenous." Through its interaction with population, and through budget constraints, geographical variables interact with other variables. While it is wrong to advocate geographic determinacy mechanically, it is equally premature to eliminate geography as an underlying variable in shaping culture, world outlook, institutions, and in affecting through them technologies and economic growth, especially before globalization has made it impossible for any nation to escape from novel ideas and new modes of production.

In light of the H-O model and Rybczynski theorem, we can see that geographical factors play an important role in production and consumption through a nation's long-term budget constraints. These constraints affect the relative prices of factors of production across different nations, thus greatly restrain the range of possible outcomes in the domains of production, consumption, culture, world outlooks, institutions, and technologies at different localities in the pre-globalized world. In this sense, geographical endowments and their changes are the true exogenous variables, because they can shape these variables but cannot be shaped by them in return.

Let's see why geographical variables can shed new light on the remaining issues in Lin's hypothesis. First, using the favorable geographical conditions of the North China Plain

we immediately can explain the emergence of the great Chinese civilization without turning to technology as a prerequisite. Second, the experiences of both the ancient Greek and the Song also point to geographical sources. The case of the ancient Greece shows that it is the spatial distribution of a population instead of the absolute size of a population (urban or rural), and the institutional arrangements that govern people's social and political interactions (democratic or autocratic) that are much more important in determining whether an economy is able to benefit from unconventional sources of growth. The geography of deep mountains and scattered plains along the shore of Mediterranean induced the ancient Greeks to organize their society in the form of trade-oriented city-states in the principle of democracy. It is not a pure accident that this spatial distribution of population and institutional arrangement of personal interaction led the Greeks closest to rationality and scientific thinking. Despite their small population size, this thinking in turn enabled them to expand their epistemic bases, and accelerated the pace of technical progress. Later this legacy helped the Europeans to adopt the new mode of invention in the 16th century during the scientific revolution.

The geographical factors also shed new light on the experience of the Song dynasty. As China gradually lost the North China Plain to the invading nomads and migrants flooded to the South, its population pressure rose sharply against shrinking taxable land acreage. The heavy burden to finance wars and the need to pay indemnity to invading nomads triggered profound social-economic changes. China was forced to depend less on agriculture and land taxes, and thus forced to transform its society into a more commercially and trade oriented one. The Song saw a rising urbanization level,

deepened divisions of labor, and extended trade ties with overseas nations. Cities as bureaucratic and military centers before the Song evolved into commercial and manufacturing centers. Even the tribute system, once tightly monopolized by the government before the Song, was induced by the prospect of lucrative tariff revenues to open up to allow the participation of the private sector and foreign merchants. China during the Song was experimenting with a new path that was promising but full of risks.

However, the subsequent changes in China's geographical boundaries actually improved the man-to-land ratio for most of the Ming and from the early to middle Qing. This improved ratio induced China to return to the safer and more familiar agrarian past. As the H-O model and the Rybczynski theorem predict, during the Ming and Qing the population became more spatially dispersed to its newly acquired territory. Meanwhile, the urbanization level fell and big urban centers shrank. China became inward looking with little interest in foreign trade and overseas exploration, as evidenced by the fact that China resumed the tribute system and closed its door to most foreign merchants during this period. Consequently, the levels of division of labor and specialization fell, and technology became stagnant.

References

- Bairoch, Paul, 1999. *Cities and Economic Development*. Chicago: University of Chicago Press, 1999.
- Barro, Robert J., 1990. "Government Spending in a Simple Model of Endogenous Growth", *Journal of Political Economy*, 98, s103-s125.
- Borthwick, Mark, 1998. *Pacific Century: the Emergence of Modern Pacific Asia*, Westview Press.

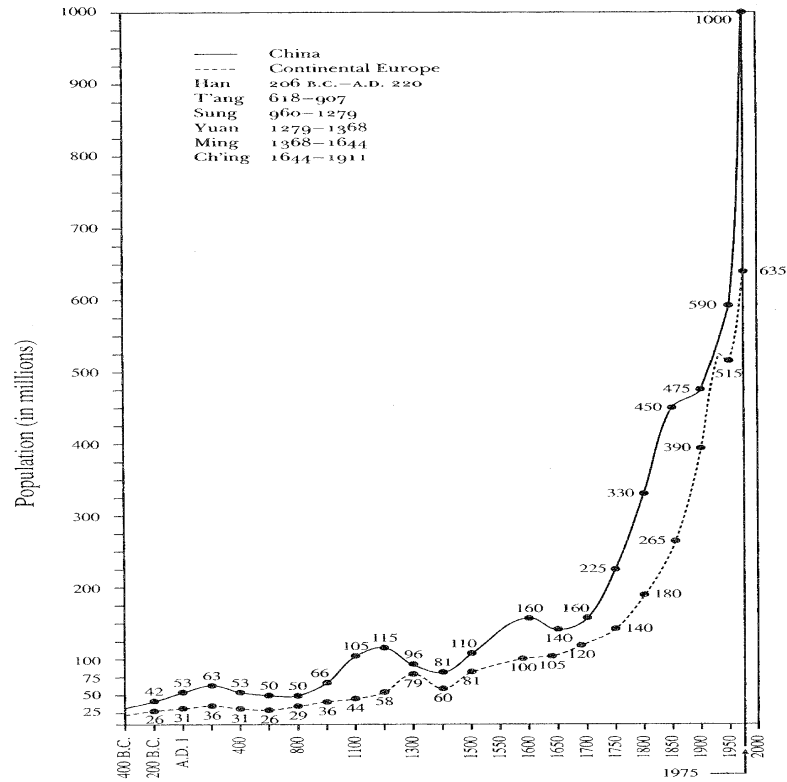
- Chao, Kang (赵冈) , 1995. *A Collection of Papers on China's Urban Development (城市发展史论集)*, Taipei, Taiwan : Lienching Press (联经出版事业公司).
- Chen,Zhichao,Qiao, Youmei (陈智超、乔幼梅) ed. 1998. *China's Economic History (中国历代经济史)* , Taipei, Taiwan : Wenjin Press (文津出版社).
- Chen, Zhiwu , 2003. *Could the Pacific Trade Bring Long-term Prosperity?* , New Wealth (新财富) , Nov. pp48 - 56.
- Cui, Lianzhong et al., ed. 1997. *The World General History (世界通史)* , Vol. I , p214, Beijing : People's Press.
- Cook, Michael, 2003. "A Brief History of Human Race." New York: W.W. Norton & Co.
- Diamond, Jared, 1997. *Guns, Germs, and Steel*, New York: W.W Norton.
- Edwards, Ronald A. 2005. "职权结构 , 产权和经济停滞 : 中国的案例。" *Chinese Economic Quarterly*, Beijing, China: The Peking University Press.
- Elvin, Mark, 1973. *The Pattern of the Chinese Past*, Stanford, California: Stanford University Press.
- Faribank, John King, 1992. *China, a New History* , Cambridge, MA: Harvard University Press.
- Gernet, Jacques 1962, "Daily Life in China on the Eve of the Mongol Invasion 1250-1276", London: Ruskin House.
- Grove, Noel, 1997. *National Geographic Atlas of World History*. Washington, D.C.: National Geographic Society.
- Gu, Chaolin et al., 1999. *Economic Globalization and China's Urban Development (经济全球化与中国城市发展)* , Commercial Press (商务印书馆).
- Huang, Chunye , 2003. *Overseas Trade during Song(宋代海外贸易)* , Beijing : The Social Scientific Documents Press.
- Huang, Ray (黄仁宇), 1999. *Capitalism and the 21st Century (资本主义与二十一世纪)*. Beijing : Sanlian Shudian (三联书店).
- Huang, Phillip C.C. 1991. *The Paradigmatic Crisis in Chinese Studies*, Modern China, 17.3 (July).
- Huff, Toby E. 1993. *The Rise of Early Modern Science*, Cambridge University Press.
- Krugman, Paul R., 1991. *Geography and Trade*, Leuven, Belgium: Leuven University Press.
- Krugman, Paul R. and Obstfeld, Maurice 2002. *International Economics, Theory and Policy*, 5th edition. New York: Addison-Wesley.
- James, Peter, and Thorpe, Nick, 1994. *Ancient Invesntions*, New York: Ballantine Books.
- Landes, David, 1998. *The wealth and Poverty of Nations*, New York: W. W. Norton & Company.

- , 2006. "Why Europe and the West? Why not China?" *Journal of Economic Perspectives*, Vol. 20, No. 2, 3-22.
- Maddison, Angus, 2001. *The World Economy: A Millennial Perspective*. OECD.
- Ricci, Matteo, 1942. *The Diary of Matteo Ricci, China in the Sixteenth Century*, trans Louis Gallagher, (New York: Random House.
- Liang, Fangzhong, 1980. *China's Historical Data on Households, Farmland, and Land Taxes (中国历代户口, 田地, 田赋统计)*. Shanghai, China: Shanghai People's Press.
- Lin, Yifu Justin, 1995. "The Needham Puzzle: Why the Industrial Revolution Did not Originate in China", *Economic Development and Cultural Change*, Vol. 43, Jan.
- Lo, Fu-chen and Yeung, Yue-man ed, 1998. "Globalization and the World of Large Cities", United Nations University Press.
- Lucas, Robert J., 1988. "On the Mechanism of Economic Development", *Journal of Monetary Economics*, 22, 3-22.
- Lucas, Robert J., 1993. "Making a Miracle", *Econometrica*, 61, 251-271.
- Mokyr, Joel, 1999. "Eurocentricity Triumphant", *The American Historical Review*, Vol. 104, No. 4.
- Mokyr, Joel. 2002. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton and Oxford: Princeton U. Press.
- Mokyr, Joel. 2003. "Why was the Industrial Revolution a Europe Phenomenon?" *Supreme Court Economic Review*, Vol. 9, Fall.
- Maddison, Angus, 2001. *The World Economy*, OECD.
- Needham, Joseph, et al., 1954-2004. *Science and Civilization in China Series*. Cambridge University Press.
- Needham, Joseph, 1981. "Science in Traditional China", Cambridge, Massachusetts: Harvard University Press, 1981.
- Qi, Xia (漆侠). 1999. *The General Economic History of China (中国经济通史)*. Beijing: Economic Daily Press.
- Ropp, Paul S., 1990. *Heritage of China*, Berkeley and Los Angeles: University of California Press.
- Shiba, Yoshinobu, 1975. "Urbanization and the Development of Markets in the Lower Yangtze Valley," in *Crisis and Prosperity in Sung China*, ed. By John Winthrop Haeger, Tucson, Arizona: The University of Arizona Press, pp13-48.
- Skinner, G. William, ed., 1977. *The City in Late Imperial China*, Stanford University Press.
- Stavrianos, L.S., 1998. *A Global History: From Prehistory to the 21st Century*. Prentice Hall.

Tan, Qixiang (谭其骧). 1982. *Collection of China's Historical Maps (中国历史地图集)*, Vol. 6 and 7, Beijing : The Chinese Maps Press.

Varian, Hal, 2004. "Review of Mokyr's "Gift of Athena". *Journal of Economic Literature*, Vol. 42, No. 3 (Sep., 2004), pp. 805-810.

Yang, Kuan (杨宽), 2003. *Studies on History of China's Ancient Urban institutions (中国古代都城制度史研究)*, Shanghai: Shanghai People's Press.



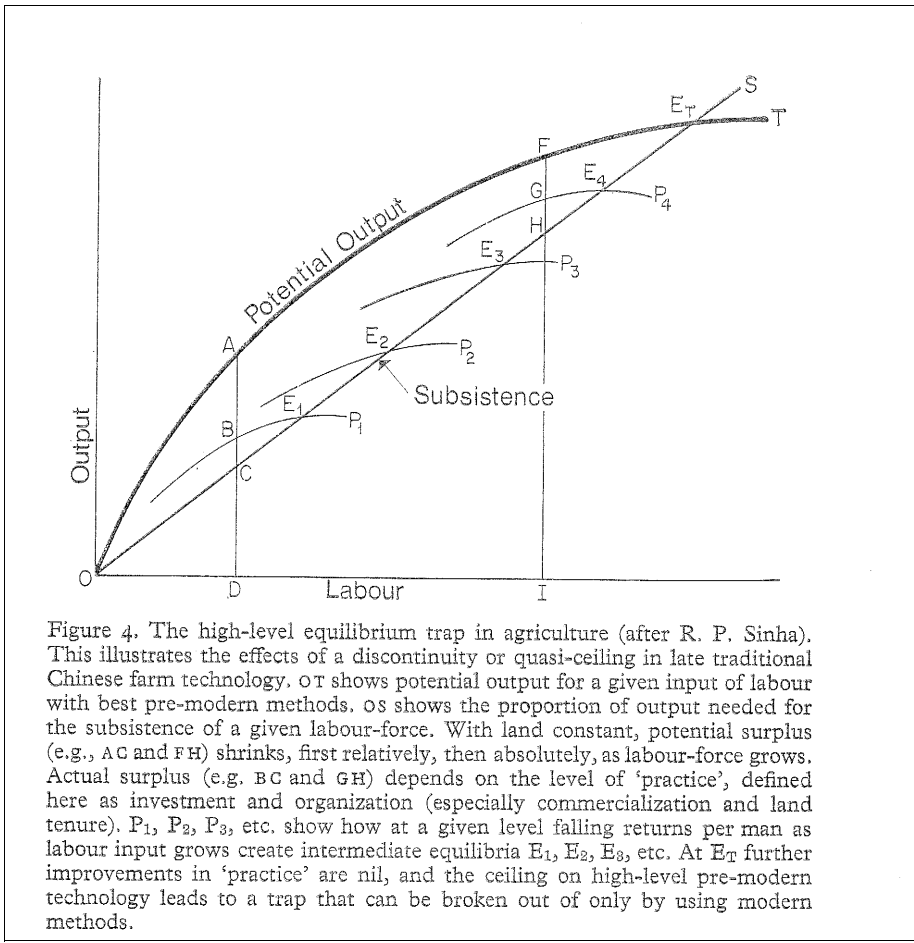


Figure 4. The high-level equilibrium trap in agriculture (after R. P. Sinha). This illustrates the effects of a discontinuity or quasi-ceiling in late traditional Chinese farm technology. OT shows potential output for a given input of labour with best pre-modern methods. OS shows the proportion of output needed for the subsistence of a given labour-force. With land constant, potential surplus (e.g., AC and FH) shrinks, first relatively, then absolutely, as labour-force grows. Actual surplus (e.g. BC and GH) depends on the level of 'practice', defined here as investment and organization (especially commercialization and land tenure). P_1, P_2, P_3 , etc. show how at a given level falling returns per man as labour input grows create intermediate equilibria E_1, E_2, E_3 , etc. At E_T further improvements in 'practice' are nil, and the ceiling on high-level pre-modern technology leads to a trap that can be broken out of only by using modern methods.