Resolving the Needham Puzzle: Let the Evidence Speak–An Explanation on the Origin of China's Tobacco Industry

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In 1954, the famous British historian Joseph Needham put forward a famous puzzle in the preface to his Science and Civilisation in China: before the 15th century, China's civilization was ahead of that of Western countries, both in terms of economics and technology; however, China suffered a disastrous decline in the subsequent era, while its Western counterparts underwent the Industrial Revolution and became the great powers of the world. Thus, Needham asked, why did the scientific revolution, which had taken place in the Western world since the 16th century, not originate in China? This paper has broken new ground both methodologically and substantively concerning the Needham Puzzle. By applying the data found in Chinese historical bibliographies of China as a proxy for the changes in the knowledge stock, this paper proposes the institutional change hypothesis and provides empirical evidence for the dynamic trend of China's technological development, thereby providing a possible explanation for the Needham Puzzle.And the loss of human capital in science and technology constitutes a necessary condition for the origin of China's tobacco industry. Because the tobacco planting industry is a labour-intensive industry, rather than a technology-intensive industry.

Keywords: Needham Puzzle; institutional change; Confucianism; Tobacco Industry

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INTRODUCTION

Joseph Needham (1900-1995) was an influential British historian who studied Asia. His magnum opus was *Science and Civilisation in China*, which was published in 1954 by Cambridge University Press. One of the intriguing issues that he proposed in this book is why the scientific revolution, which had taken place in the Western world since the 16thcentury, did not originate in China[1]. In fact, before the 15th century, China was ahead of Western nations, both in science and in technology. Furthermore, it is widely considered that the elements contributing to the Industrial Revolution in late-18th century England also existed in China[2]. However, China suffered a disastrous decline in the 19th century with both an economic downturn and political turbulence, while its Western

counterparts underwent the Industrial Revolution, becoming the great powers of the world. The question put forward by Needham in 1954 is known as the "Needham Puzzle."

The Needham Puzzle needs to be analysed not only from the perspective of economic growth but also from the vantage points of China's institutions, culture, history, society, and politics. Four possible explanations of the Needham Puzzle are discussed widely in the literature. These explanations include the imperial examination system hypothesis[2], the high-level equilibrium hypothesis[3], the geographical endowment hypothesis[4], and the property rights hypothesis[5,6]. We discuss these four explanations in detail in a later section of this paper. Though each of these hypotheses may provide a largely plausible explanation for the Needham Puzzle, scholars continue to debate which of them is the most credible, as none can be proved by the available empirical data.

To help solve the Needham Puzzle, our paper proposes an alternative explanation, which we term the institutional change hypothesis. Our hypothesis incorporates North's (1990) institutional change theory[7], as well as the implications of China's single-authority structure[8]. We argue that historically, the ruling class in China focused on the development of Confucianism, which helped incumbent rulers build a strong bureaucratic system and the familial patriarchal system to manage a geographically massive empire while ignoring the development of science and technology, ultimately leading to the loss of human capital in terms of technological innovation. Without a sufficient accumulation of human capital, the Industrial Revolution could not occur in China. Meanwhile, with the introduction of American crops such as corn and potato, the Chinese population has achieved explosive growth from less than 100 million to more than 200 million during the 17thcentury. TheGrowthof Low skilled labour force andthe loss of human capital in science and technology provide a fertile soil inhuman capital for the development of the tobacco industry. Because the tobacco planting is a typical labour-intensive industry, rather than a technology-intensive industry[9,10]. Unlike previous studies that focus on qualitative analyses for solving the Needham Puzzle, our paper is the first to provide empirical evidence of the dynamic trend of China's technological development. By utilizing the data of China's historical bibliographies as a proxy for the changes to knowledge stock, we find that science and technology literature in China has long been in low supply, while a considerable amount of the literature has focused on Confucianism studies. This lack of science and technology literature implies that innovations in science and technology did not play an important role in ancient Chinese culture. Additionally, we also discover a negative correlation between the stock of Confucian literature and that of science and technology. The empirical results support our institutional change hypothesis. Our paper provides an institutional analysis perspective to explain the Needham Puzzle and innovatively applies empirical data to support our theoretical hypothesis. The paper thus contributes to the literature that attempts to answer the long-standing Needham Puzzle.

The remainder of this paper is organized as follows. The following section introduces the four major existing hypotheses of the Needham Puzzle and provides counterarguments to each. Next, we propose our institutional change hypothesis using institutional analysis and the argument of China's single-authority structure. In section 4, we apply an empirical analysis, which supports our theoretical hypothesis. Finally, in section 5, we present the study's conclusions.

LITERATURE REVIEW: HYPOTHESES OF THE NEEDHAM PUZZLE

Chinese civilization has lasted for nearly five thousand years. Historically, many important inventions originated in ancient China, and during the 14th century—approximately the time of China's Yuan and Ming dynasties—China held a leading place in science and technology. For example, the inventions of papermaking, gunpowder, the compass, and printing with movable type were all created by the Chinese. In addition, the shipbuilding industry in Imperial China (c. 14th century) also reached its height, far exceeding that of contemporary Europe[11]. Furthermore, China's per capita output of iron in 1080 was approximately five to six times more than that of Europe[12]. This evidence shows that up until around the middle of the 14th century, China was technologically more advanced than its Western counterparts and was also more so than the medieval Islamic world[13]. However, during the

17th century—about the time of the Ming and Qing dynasties—economic growth in Europe increased rapidly during the Industrial Revolution, while China stagnated. During this era, China continued to be dominated by its textile industry. Huang (1988) argues that economic development in China during the 17th century was trapped in involutional growth[14] ("Involutional growth" refers to growth generated by extended repetitive work[15](Geertz, 1963). Huang (1988) uses this concept to explain the inefficient economic states due to the repetitive work found in cotton plants and in sericulture industries in the southern area of the Yangzi River during the Ming and Qing dynasties[14].), implying that resource allocations were highly inefficient. As posed by the Needham Puzzle, many scholars have asked how it is possible that China played such a leading role in science and technology in the 14th century but experienced such a disastrous decline afterward, even becoming something of a semi-colonial country of European powers in the late Qing dynasty (1644-1912).

Indeed, the Needham Puzzle has been widely discussed and debated. As mentioned above, four main hypotheses have been put forward to answer this conundrum. One of these hypotheses is the imperial civil examination hypothesis, proposed by Lin (1995), who argues that the rigid imperial civil examination system of ancient China contributed to an imbalance in human capital accumulation[2]. The imperial civil examination system began in the Sui dynasty (AD 581-618) and ended in the Qing dynasty (1644-1912). Since the examination system of ancient China focused on the study of rhetoric skills and Confucianism analysis, intellectuals, driven by career concerns, devoted their time and effort to these two subjects. This led to a loss of human capital in terms of technological innovation. Although this hypothesis partially explains variations in human capital allocation across subjects in ancient China, it ignores the fundamental question as to why the ancient empire of China favoured Confucianism instead of innovation, as well as how this bias was formed. Our proposed institutional change hypothesis, which we discuss in the following section, begins to fill this gap in the academic literature by answering these two questions.

The second possible explanation for the Needham Puzzle is the high-level equilibrium hypothesis (Yao, 2003). This work considers the factor of economic scale and adds an additional industrial sector to Elvin's (1973) high-level equilibrium trap model[3,16]. In the high-level equilibrium hypothesis, Yao(2003) argues that traditional China relied on the development of the agricultural sector, which hindered industrial development. The high returns from the agricultural sector expended most of China's human and physical capital, resulting in insufficient resource allocation to the industrial sector. By applying the high-level equilibrium trap theory, Yao provides a mathematical logic model for the Needham Puzzle. However, Yao ignores the fact that technological innovation at the time occurred not only in the industrial sector but also in the agricultural sector and that neither occurred in ancient China.

Another possible explanation is the geographical endowment hypothesis. This hypothesis argues that particular geographical environments and resource endowments are the necessary conditions and basic constraints in the process of economic development [4]. The higher a country's natural agricultural endowment is, the more likely it is that the country will remain an agricultural society. It is a fact that during the 14th century, China had an advanced textile industry, which relied on the agricultural sector, and thus remained a traditional agrarian society with a high level of self-sufficiency. Thus, without a desperate need to change, there was no incentive for a scientific revolution in China. It is important to note that even though both the geographical endowment hypothesis and the high-level equilibrium hypothesis consider the existing prosperous agricultural sector as the main reason hindering the possibility of technological innovation, the former focuses more on the exogenous natural geographical environment, whereas the latter concentrates on endogenous resource allocations.

The fourth hypothesis, by Huang (1997) and Kou (2009), focuses on the issue of property rights. Both argue that in ancient China, the idea of property rights was weak. Unsecured property rights led to uncertain returns from innovations; thus, people did not have substantial incentives to engage in time-consuming science and technological research, ultimately resulting in underdeveloped technological development[5,6].

Even though all four of the above hypotheses partially help explain the Needham Puzzle, none is supported by **empirical data**. Thus, which

hypothesis is most credible is still widely debated. To fill this academic void, the current paper aims to provide a convincing explanation to help solve this historical conundrum. We do so by incorporating North's (1990) institutional change theory [7] with the idea of China's single-authority structure [8], proposing a new model, which we term the institutional change hypothesis.

INSTITUTIONAL CHANGE HYPOTHESIS

Institutional Change Theory

Before introducing the details of our proposed institutional change hypothesis, we must first briefly introduce North's (1990) institutional change theory, as we argue that the Needham Puzzle should be analysed from an institutional perspective. North (1991,p. 97) defines institutions as "humanly devised constraints that structure political, economic and social interactions" [15]. North's(1990) institution change theory argues that existing institutions are required to create an efficient market with low monitoring costs and low transaction costs[7]. However, a ruling class that controls the political system prefers to structure institutions to maximize their personal benefit, rather than furthering all of society. Thus, the ruling class determines the relative prices of production factors to assist the sectors which, in turn, will provide them with the highest possible profits. Additionally, members of the ruling class expend resources and invest in acquiring knowledge and skills that increase their own wealth. The interplay between the institutions and the acquisition of knowledge shapes long-term development, determining future economic growth. If the political actors in power create institutions for their own benefit at the historical outset, they are then reluctant to change those institutions; it is only when those in control believe that institutional changes will significantly benefit themselves that they have the motive to develop new knowledge and to structure new institutions. The path-dependent nature of this system is a process of institutional change in which the old institutional framework provides the opportunity set for new organizations[17]. The trajectory of social development may be limited by the initial condition, yet the consequence of an evolving institutional framework may produce erratic economic growth and lead to the different possible long-term equilibria of a process.

Based on North's (1990) institutional change theory, we argue that this theory not only explains the evolution of the institutional framework but also applies to the development of scientific and technological innovation. When those in charge have a vested interest in acquiring knowledge in science and technology, they have the incentive to invest in and promote scientific and technological innovation. On the other hand, if innovation might lead to a threat to their power, the ruling class would hamper innovation[18]. This is especially common in non-democratic systems[19], and it is exactly what occurred in Imperial China. When the emperors obtained the benefits from the existing Confucianism-dominated institutions, they were reluctant to change those institutions, and thus they ignored the developments taking place in the fields of science and technology globally. Therefore, we must ask what the main focuses of the Chinese emperors were, and why they favoured Confucianism. To answer these questions, it is necessary to introduce the single-authority argument to understand the historical and cultural background of China.

The Single-Authority Argument

Institutions and culture evolve in a complementary way with mutual feedback effects[20]. In the context of ancient China, this evolution implies the relationship between a single authority and Confucianism.

Geographically speaking, Mainland China covers an integrated and relatively flat area, with natural barriers on its eastern, western, and southern borders, all of which have thwarted potential enemies. On its southern border, there are tall mountain peaks and deep valleys; to the west, there are deserts; and lastly, the western Pacific Ocean sits to China's east. What is left is its northern border, and here, Emperor Qin Shi Huang, who unified China in 221 BC, constructed the Great Walls along China's northern border to deter potential invaders. Taken together, the four borders of Mainland China create a self-supporting and unified area that can be occupied and ruled by a single centralized political power[8]. According to Hsiung, the geographical features of China led to a single political authority and the ideology of unification. To control such an enormous country and to develop a simple set of ideas

accommodating regional differences, China's emperors developed Confucianism, which aided them in running a large bureaucratic system that regulated the public. Emperor Wu of Han (156-87 BCE) implemented the widespread use of Confucian ideals to achieve the goal of unifying the thoughts of the general public, which also effectively and efficiently maintained imperial power. Since the time of the Han dynasty (202 BCE-220 CE), then, Confucianism has been the dominant ideology in China, influencing the Chinese people for centuries.

At this point, it is necessary to ask why Confucianism became the mainstream, dominant ideology in Imperial China. In fact, in addition to Confucianism, there have been three other important ideologies for China: Taoism, Mohism, and Legalism. However, the arguments of these other ideologies can be seen as being potentially against the interests of the emperors. For instance, Taoists advocated inaction and letting things take their own course, which is not conducive for rulers who involve themselves and manipulate political and economic structures. The Mohists stressed universal love, equality, and the veneration of the wise. Legalists emphasized that everyone was equal under the political regime. If China was to follow, either the Mohists or the Legalists to emphasize equality, the emperors would not have been able to maintain their monopolistic power and to maximize their own utility. What is left, then, is Confucianism.

The ideas of Confucianism are consistent with the interests of the ruling class. They emphasized unity and the natural law of power, convincing the public that the emperor was "chosen," so that it is in their best interest to follow the emperor's absolute control under any circumstance. Confucianism also advocated benevolence and courtesy as the heart of human behaviour, thus facilitating the implementation of government policy[8]. Moreover, Confucianism focused on ethical laws, obliging all to be hardworking and obedient for the sake of the emperors—dissent was against the laws of Confucianism. Through a system of punishments and incentives, Confucianism enabled the emperors to strengthen their imperial powers and to control the intellectuals, eliminating the possibility of creative destruction (The discussion of creative destruction can be found in Schumpeter (1990)[21].). Therefore, Confucianism's so-called "cardinal guides" and "constant virtues" formed strong bureaucratic and familial patriarchal systems, providing the emperors with *de facto* power to control and punish citizens. The major consolidation of Confucianism was further strengthened during the establishment of the imperial examination system in the Sui and Tang dynasties (581-907 CE). Here, Confucianism was considered the most important subject on the exam. Therefore, Confucianism gradually became the mainstream thought of Chinese culture, continuously enforcing the single authority of the emperor.

Institutional Change Hypothesis

On the one hand, the results of China's Confucianism-dominated culture made the most of the society's human capital devoted to the subjects of the humanities and social sciences (The disciplines of the humanities and the social sciences refer mainly to the fields of literature, art, ethics, philosophy, politics, and so forth.),ignoring the developments in the fields of science and technology. On the other hand, Confucianism's tenets suppressed innovation. For instance, in general, Confucian doctrines emphasize cardinal guides and constant virtues, encouraging social stability; moreover, they are against taking risks and embracing uncertainty, thus preventing the possibility of destructive innovation. In addition, during the Han dynasty, Confucianism gradually incorporated the thoughts of Buddhism and Taoism. The tenets of Buddhism and Taoism are to discourage the desires of the people and to advocate for letting things take their own course. These ideas are beneficial for the ruling class to control society at the grassroots level. Thus, we argue that Confucianism stifled the development of science and technology in ancient China, leading to biased human capital accumulation in Confucianism studies and suppressing innovation. As mentioned previously, the institution system can result in changes in the knowledge stock and the relative prices of factors of production which, in turn, shape the structure of knowledge stock, thereby influencing economic growth[7]. The ruling class would have the incentive to develop new technology only if they would be certain that they could continue to prosper. The more wealth the monopolistic powers have, the greater their preference to avert any risks in order to maximize their wealth[22]. Since the emperors in power were

benefiting from the institutions in place, and the country was dominated by the doctrines of Confucianism leading to a strong single authority and growing their monopolistic power, they were unwilling to change the existing Confucianism-dominated culture and institutions. This resulted in insufficient human capital for the accumulation of scientific and technological innovation. The development of science and technology stagnated in a steady-state equilibrium, without sufficient elements to initiate an Industrial Revolution. This is what we term the institutional change hypothesis. We argue that this hypothesis better answers the Needham Puzzle.

EMPIRICAL ANALYSIS

Hypotheses

To examine the robustness of the institutional change hypothesis for the Needham Puzzle, we collect the historical bibliographies of ancient China over nearly two thousand years. Next, we use changes in the volumes of the literature dedicated to science and technology and the volumes dedicated to Confucianism as a proxy for the changes in the structure of knowledge stock in the different dynasties to capture the trend of the development of science and technology.(A similar approach can be found in Mokyr (2005) and in Chaney (2016). Both use the number of scientific and technological items of literature as an indicator to capture the change in the development of science and technology, capturing the evolution of institutions[23,24]. Mokyr (2005) studies the influence of the Enlightenment on the Industrial Revolution by utilizing 17th- and 18th-century sci-tech periodicals[23]. Chaney (2016) collects the numbers of books in the Middle East from the 10th to the 17th centuries to explain the end of the Golden Age of Islam. During this period, he finds that the number of sci-tech books declined while the number of religious books increased, implying that the political power of the religious elite grew, thus hindering the development of science and technology[24].)The proportion of science- and technology-related literature in all ancient Chinese works demonstrates the degree of development of science and technology in each dynasty, indicating the trend of innovation. Thus, our first hypothesis is as follows:

The small proportion of Chinese scientific and technolog ical literature is mainly due to the innovations in science and technology that were long ignored by the ruling class in China.

Moreover, since the emperors advocated for Confucianism as the dominant ideology in ancient China, we believe that the more the literature related to Confucianism there was, the less human capital was expended in the fields of science and technology. In other words, the development of Confucianism hindered the development of science and technology, thus explaining the Needham Puzzle. Thus, second, we hypothesize the following,

The proportion of Confucian literature is negatively correlated with the proportion of science and technology literature.

Data from Ancient Chinese Bibliographies

To capture institutional change and scientific and technological development, we collect the historical bibliographies in China from 202 BCE to 1781 CE, including the seven of the most authoritative ancient bibliographies. Since the time of the Western Han dynasty (c. 100 BCE), Chinese emperors of successive dynasties would appoint the most knowledgeable scholars to compile and edit the literature of the previous dynasty. This custom created a major historical record, enabling us to understand the stock of knowledge in each dynasty. For the most part, Chinese historians believe there are 24 official historical kinds of literature written in a biographical style which, taken together, are called the *Twenty-Four Histories*. Among them are seven official historical bibliographies, including *HanShu*, *SuiShu*, *JiuTangShu*, *XinTangShu*, *SongShi*, *MingShi* and *QingShiGao*. However, since the bibliographies in *MingShi* and *QingShiGao* only represent incremental changes of knowledge in each dynasty rather than the knowledge stock, this paper uses the *SiKuQuanShuZongMu* instead to represent the knowledge stock of the Qing dynasty and the incremental data as the approximate reference of the knowledge stock of the Ming dynasty (see Appendix for detailed information).

By using the number of volumes of literature as a unit, we can calculate the number of volumes in each dynasty to observe the trend of the knowledge stock[25]. Table 1 provides the information of each bibliography, including the dynasty to which it belonged, the number of volumes of literature in

each bibliography, and the approximate population size in each dynasty.

Figure 1 demonstrates the general trend of knowledge stock, showing that the number of volumes steadily increased from the Western Han dynasty to the Song dynasty, even though the population sizes varied. Although the population rose only four million in the Song dynasty compared to the Western Han dynasty, the knowledge stock reached its peak in the Song dynasty—nine times the amount of the Han dynasty. Following the Song dynasty, we see that there was significant population growth; however, the development of knowledge stock actually decreased over time. This may be attributed to the foreign invasions that occurred in these eras (i.e., the Mongolian invasion during the Yuan dynasty, and the Manchu invasion during the Qing dynasty).

Table 1
Data Information

Bibliographies	Dynasty	Population (Thousand)	Literature(Volumes)
HanShu·YiWenZhi	The Western Han (282 years) (202 BCE-80 CE)	15,000-60,000	13,269
SuiShu·JingJiZhi	Sui (116 years) (502-618 CE)	56,000-58,000	43,404
JiuTangShu·JingJiZhi	Early era of Tang (103 years) (618-721 CE)	22,000-90,000	51,852
XinTangShu·YiWenZhi	Tang (442 years) (618-1060 CE)	22,000-90,000	82,384
SongShi·YiWenZhi	Song (294 years) (960-1254 CE)	58,000-100,000	119,972
MingShi·YiWenZhi	Ming (276 years) (1368-1644 CE)	60,000-197,000	105,974
SiKuQuanShuZongMu	Early era of Qing (145 years) (1636-1781 CE)	119,000-275,000	79,309

Note: The population data were collected from *History of Chinese Population* (Ge, 1991) [26], which provides the estimated numbers of the population peaks and valleys for each dynasty.

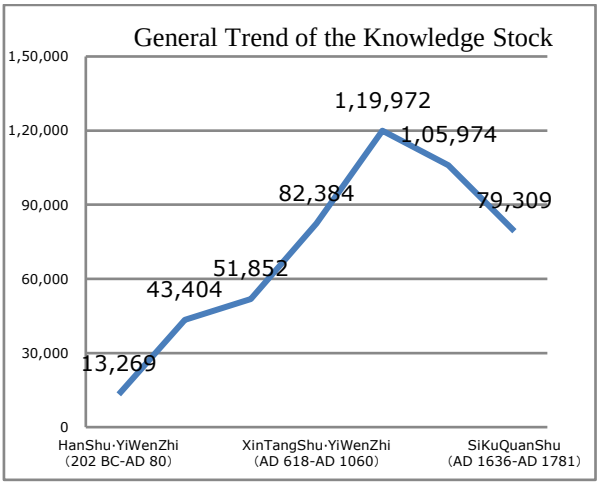

Figure 1. General Trend of the Knowledge Stock

Based on the classifications of the volumes in the bibliographies, the volumes of scientific and technological literature can be counted, showing the development of science and technology in each dynasty (The subjects classified as science and technology include agriculture, astronomy, almanac, foresight, miscellaneous divine, necromancy, Chinese medical classics, Chinese medicine and pharmacy, pharmaceutical formulas and infusion and math. This classification follows Yu (2009)[27].). As shown in Figure 2, the proportion of scientific and technological books began to decline with the Han dynasty. Although the proportion of scientific and technological literature increased slightly to 10.95% in *XinTangShu*, there was still a significant drop compared with the two previous dynasties (the Han and Sui dynasties). Therefore, from the beginning of the Han dynasty to the Song dynasty, the stock of knowledge increased, yet knowledge of scientific and technological innovations declined. We also see that from the time of the Song dynasty, the amount of knowledge stock and the amount of information regarding scientific and technological innovations both declined. Figure 2 also shows that the development of science and technology began to stagnate with the Song dynasty, coinciding with the time point discussed in the Needham Puzzle. During this period, Western Europe became the world's intellectual innovation centre, beginning with the early Renaissance, and continuing through the Enlightenment and the Industrial Revolution periods. Especially during the Industrial Revolution, the knowledge system in the West experienced a qualitative change, leading to a watershed of

scientific and technological developments and breakthroughs, separating the knowledge stock of the West from that of China.

Empirical Discussion

Changes in the scientific and technological knowledge stock seen in Figure 2 demonstrate the trend of scientific and technological development in China. The main reason for the low proportion of science and technology literature is that the ruling class revered Confucianism to build their single authority, creating a situation where innovations in science and technology were ignored. This finding is consistent with our first hypothesis. The monoculture of Confucian thought was strengthened through the centralization of imperial power. During the dynasty of the Spring and Autumn period (770-476 BCE), competition between many types of ideas was fierce. According to the *HanShu·YiWenZhi*, there were 189 different competing lines of thought. However, beginning with Emperor Wu of Han, who advocated for Confucianism as the sole dominant policy, there were only 12 competing thoughts left in *SuiShu·JingJiZhi*. Further, of the hundreds of competing thoughts during the Spring and Autumn period, we are left with the four main lines of thought discussed previously: Confucianism, Mohism, Taoism, and the Legalism. Figure 3 shows the volumes of literature dedicated to each thought, implying the structure of knowledge in each dynasty. It seems that Mohism and Legalism were never in the mainstream in Chinese society. The proportion of literature of these two lines of thought is only approximately 10% (Figure 3). However, after the Han dynasty, the share of Confucian literature accounted for approximately 39%, and this rose dramatically to 70% in the Song dynasty, gradually playing the leading role in Chinese society.

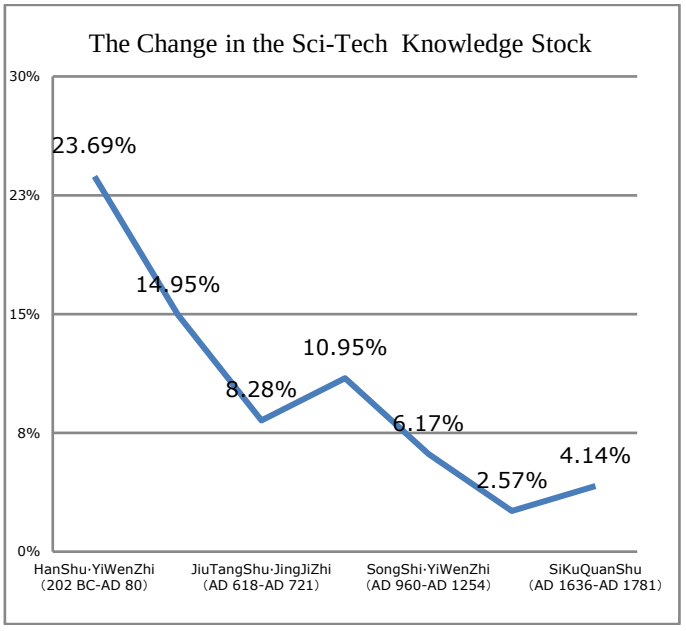

Figure 2. Changes in the Scientific and Technological Knowledge Stock

Additionally, Figures 2 and 3 show that the amount of Confucian literature and the amount of literature dedicated to science and technology are negatively correlated. This finding verifies our second hypothesis. Under the centralized system, the emperor preferred to maintain the stability of the system to preserve monopolistic power. The development of Confucianism strengthened the incumbents' ruling power. However, it also suppressed scientific and technological innovation, making the Industrial Revolution far less likely in China.

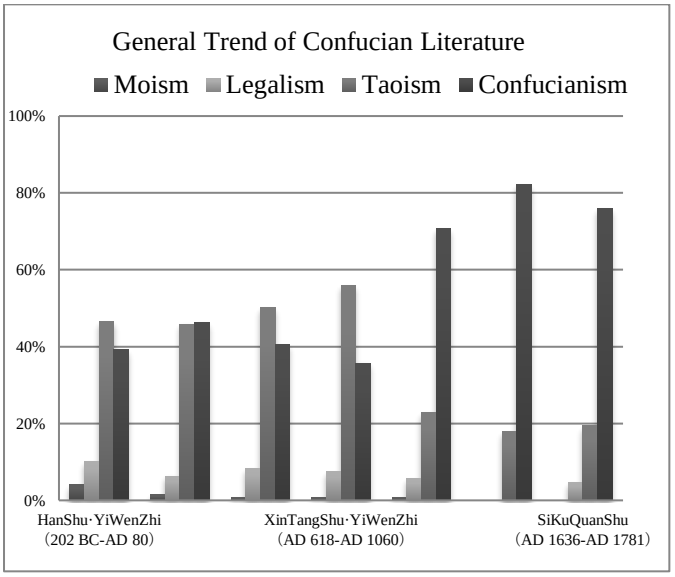

Figure 3. General Trend of Confucian Literature

Extension

Figure 2 also shows that the quantity of CHPL books in every bibliography is of a quite high (CHPL literature refers to those items related to Confucianism, history, philosophy and literature.). The greatest proportion can be found in *MingShi·YiWenZhi*, approximately 97%, implying that the ruling classes in China ignored the development of science and technology for a long time. Our data also counters the argument of the many historians who state that "banning hundreds of schools of thought" and a "Confucian-only dominant policy" began at the beginning of the Western Han dynasty and that Confucianism became the mainstream thought of the society at that time (A detailed discussion can be found in Zhang (2009) [28].). These arguments are disputed by Figure 3, which shows that until the end of the Tang dynasty, the quantity of literature on Confucianism and Taoism were approximately the same; this demonstrates that Confucianism and Taoism were in active competition with each other during the Western Han dynasty. However, we find that the proportion of CHPL books increased dramatically in the Ming and Qing dynasties, to more than 95% (Figure 2). This rapid upward trend might be attributed to the ruling classes' growing insecurities regarding their power and their level of control (The motives of the emperors can be attributed to the dynamic mechanism of risk-aversion preferences, as explained in Varian (1992) [22].), for instance, with the establishment of the Dongchang and Xichang (the espionage agencies under the leadership of the Ming dynasty) and the ban on maritime trade and communication with foreign countries. The ruling classes' insecurities grew even stronger during the Qing dynasty, when the Qing ruling class was a minority group but became China's dominant class. In this era, both the frequency and extent of eliminating scholars with different political opinions by means of a literary inquisition was at its highest level in history (According to Archives on Literary Inquisition in Qing Dynasty, the literary inquisition peaked during the reign of Emperor Qianlong (1711-1799), at about the same time as the Industrial Revolution. There were more than 130 guilty verdicts in criminal trials, and in 47 trials, the accused were put to death.). All these phenomena reveal the ruling class's motives to suppress the development of science and technology. However, as we know, major changes were taking place in politics, the economy, science, technology, and culture in the West following the Industrial Revolution, and Western society was becoming more open to new technological advancements. In contrast, China became more and more closed off to the rest of the world. Until Opium War, China was forced to open its major ports. Disappointment with the military losses convinced Chinese elite that a self-strengthening movement must be aroused.With the aid of western Protestant missionaries and experts, radical changes began to occur in Chinese traditional culture. The whole society gradually took the initiative to accept the western sciences and focus on technological innovation once again (For important contributions to the discoveries of late Qing reformism and modern science, see Elman (2005) [29].). This argument of historical scholarship was also consistent with the bibliographical evidence. After the Xinhai Revolution of 1911 (The Xinhai Revolution, also known as the Chinese Revolution or the Revolution of 1911, was a revolution that overthrew China's last imperial dynasty (the Qing dynasty) and established the Republic of China.), China had put an end to the single-authority era. And according to the Bibliography o*f the Republic of China*, the proportion of CHPL books remained at approximately 89% from 1911 to 1949 but had decreased to 70% by 2015 (The quantity is based on Bibliography of the Republic of China, a series of 24 categories compiled by the libraries of the National Library of China. This bibliography includes 124,000 books published between 1911 and 1949.).

CONCLUSIONS

Our paper innovatively proposes the institutional change hypothesis to explain the Needham Puzzle by applying both theoretical and empirical analyses. In this study, we incorporate the single-authority argument and North's (1990) institutional change theory. In addition, empirically, we apply the volumes of historical literature related to science and technology as well as those related to Confucianism as a proxy for the structure of knowledge stock, allowing us to capture the trend in the development of science and technology knowledge. Our analysis shows that the volumes of Confucianism-related literature are negatively associated with the volumes of scientific and technological literature, and also demonstrates that

technological innovation was long ignored by the Chinese ruling class. Specifically, as bibliographies are an inventory of social knowledge stock, by taking their information as a starting point, we can capture the society's knowledge structure during specific periods. By gathering and selecting the amount of knowledge at different time points, we can illustrate the evolution of major lines of thinking. This paper applies this approach from an institutional analysis perspective, allowing us to provide an answer to the Needham Puzzle. Furthermore, if we consider former theses as a benchmark for the Needham Puzzle, comparatively speaking, our study is the first to present such evidence. Letting the bibliographical evidence speak for itself methodologically should be more significant than answering the Needham Puzzle.

The answer of ignoring science and technology by the ruling class also providedaplausible explanation the origin of China's tobacco industry. The tobacco industry employed a large number of low-tech labour forces, therefore, an appropriate industrial structure adjustment will achieve a labour market equilibrium.

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Author Declaration

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