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Neo-Confucianism and the rise of science and technology in Medieval China

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Abstract

The Song dynasty (960–1279 A.D.) witnessed a surge of scientific and technological development, notably in mechanical engineering, metallurgy, shipbuilding and nautics, civil engineering, manufacturing, etc. At the same time, Neo-Confucianism, which advocated 'upholding heavenly principle and annihilating human desire', flourished in Song time. The rise of Neo-Confucianism as a conservative movement appeared fundamentally at odds with the splendid technological achievements in Medieval China. To address the question, we dismantle the notion of Neo-Confucianism in the Song dynasty context by constructing the indices of the Neo-Confucian spirit characterized by the pursuit of principle (*li*), broad learning, and scepticism on the basis of Song Confucian works recorded in the *Records of Song and Yuan scholarship* (*Song Yuan xue an*). Our results show that the popularity of Neo-Confucianism facilitated the development of science and technology during the Song period. Using historical Confucian academy data compiled from several extensive surveys, we show that the vigorous development of the Confucian academies served as a channel to propagate the Neo-Confucian spirit in a locality, thereby influencing the scientific and technological output of the Song era.

KEYWORDS
Confucian academies, neo-Confucianism, science and technology

JEL CLASSIFICATION
N00, O10, Z10

> 'The Neo-Confucians arrived at what was essentially an organic view of the universe … This was a world-outlook consonant with science indeed'.
>
> Joseph Needham, 1956 [1]

Religion has typically been regarded as the main impediment to the development of science. The confrontation between religion and science is depicted in anecdotes of celebrated cases such as that of Giordano Bruno (1548–1600), Galileo Galilei (1564–1642), and Charles Darwin (1809–82), couching their relationship in a vicious 'conflict thesis' or simply a 'warfare model'.[2] The conflict thesis is supported by a recent study by Chaney that attributes the decline of scientific output in the medieval Islamic world to 'Sunni Revival'.[3] However, given multiple shortcomings of the conflict thesis, such as the neglect of rigorous analytical frameworks in both science and religion, etc.,[4] Hooykaas and Jaki reject the conflict thesis and claim that Protestantism, especially Calvinism, had made the development of modern science possible.[5] The historical relations between religion and science are more complex than a simple 'conflict' or 'harmony' thesis suggests.[6] A similar controversy on the relationship between Confucianism and Chinese science is debated in the historical literature[7] and has lately gained renewed interest among economists.[8]

The term 'Confucianism', coined by the Jesuits in the seventeenth century, contains numerous interpretations. It can be interpreted as *Ruxue* to describe the study of Confucian classics, or Confucian culture, that is, a set of behavioural norms prescribed by Confucian ethic values, or even *Rujiao* (the religion of Confucius). What should be observed in these three understandings is that Confucianism was never a transcendent religion; although the notion of humanized 'heavenly mandate' inherited from antiquity could somehow resemble God, there are stark differences. One exception is the Jesuit missionaries to China in the seventeenth century who attempted to integrate Neo-Confucianism as a theistic religion to facilitate their translation projects.

During the Song dynasty, Neo-Confucianism (*Li xue*), which emphasized the doctrines of human morality, human nature, and the cosmos, originated from the philosophical teachings of the Cheng brothers, that is, Cheng Hao (1032–85) and Cheng Yi (1033–77).[9] Unlike the traditional Confucian scholars of the Han (202 B.C.–220 A.D.) through the Tang (618–907 A.D.) dynasties, who were primarily engaged in commenting on the Confucian classics with philological methods

[1] Needham, *Science and civilization*, vol. 2, p. 412.

[2] For example, Draper, *History of the conflict between religion and science*; White, *A history of the warfare of science*; Simpson, *Landmarks*.

[3] Chaney, 'Religion and the rise and fall of Islamic science', *Harvard University Working Paper* (2016). https://economics.sas.upenn.edu/system/files/2018-09/science_2016.pdf

[4] Ferngren, *The history of science and religion*.

[5] Hooykaas, *Religion and the rise of modern science*; Jaki, *Science and creation*.

[6] Lindberg and Numbers, *God and nature*; Brooke, *Science and religion*.

[7] Ibid.; Chan, 'Neo-Confucianism and Chinese scientific thought'; Ren, 'Ming Qing lixue pingyi'; Yue, *Rujia wenhua yu zhongguo gudai keji*.

[8] Landes, 'Why Europe and the West'; Mokyr, *A culture of growth*; Ma, 'Knowledge diffusion'.

[9] See Bol, *Neo-Confucianism in history*, p. 78. This philosophical movement has been given different Chinese names because of the different philosophical content emphasized in different periods. In order of their appearance: *Dao xue* (the learning of the Way), *Li xue* (learning of the principles that give all things their coherence), *Xin xue* (the learning of the mind), and sometimes merely *Sheng xue* (the learning of the sages). The focus of this paper is *Li xue*.

(*xungu*), the Neo-Confucians of the Song time were devoted to liberal and creative interpretations of ethical and spiritual values (*yili*) found in traditional Confucian philosophy. At the same time, Neo-Confucians were confronted with a major problem that early Confucians had not addressed: how to combat the nihilist metaphysics of Buddhism which had gained immense popularity since the Tang dynasty, thereby posing a threat to the Confucian orthodoxy as the state ideology. Consequently, the Neo-Confucians excluded theistic religions from the competition of ideology for state endorsement on the one hand, and restored Confucianism with a new philosophical foundation by embracing some Buddhist and Daoist notions on the other.

Concurrently, the Song empire witnessed 'the greatest flowering of indigenous Chinese science'.[10] Inarguably, Chinese science and technology achieved a new pinnacle in the Song Dynasty, vastly exceeding that of Europe at the same time. Movable-type printing, gunpowder, and the compass, three of the Four Great Inventions, considered by Francis Bacon to accelerate the transition from the Middle Ages to modern society in the West,[11] were all revolutionized and applied to practice in large scale during the Song Dynasty. Specifically, during Emperor Renzong's reign (1010–63 A.D.) of the Northern Song Dynasty, Bi Sheng (972–1051) invented movable-type printing, which was about 400 years ahead of Gutenberg's movable-type printing in Germany and was considered a revolution in the history of world printing. In addition, the well salt industry, textile industry, and other technologies were also quite developed. In the thirteenth century, for instance, a hydraulic textile machine was used to weave hemp thread, with similar machines in Europe being used in the 1700s.[12] Joseph Needham was impressed by the grandeur of the Song Dynasty's scientific and technological achievements. According to his words, 'Whenever one follows up any specific piece of scientific or technological history in Chinese literature, it is always at the Sung dynasty [13] that one finds the major focal point. This is as true for the applied as for the pure sciences'.[14] A quantitative study conducted by Jin et al. also reveals that the Northern Song Dynasty experienced a significantly higher pace of advancement in science and technology than other dynasties.[15]

The debate about whether Neo-Confucianism is a stepping stone or a stumbling block for science and technology has not been settled in the literature. The emphasis on introspection and the cultivation of moral perfection according to the Confucian traditions is one of the defining characteristics of Neo-Confucianism. It is consequently perceived that Song Neo-Confucianism fostered a social atmosphere conducive to internal investigation rather than the external quest of knowledge, which runs counter to the experimental methods advocated by modern science and thus stifles the development of science.[16] The imperial examination system (*keju*) is blamed for further diminishing the urge to study science majors and shifting literati's interest towards becoming officials.[17] Similarly, a statistical study finds that the elites of the Northern Song Dynasty paid less attention to technology after the 1120s, and attributed this to the rise of Neo-Confucianism, which stressed morality above technology at that time.[18] In a study using Ming and Qing data,

[10] Ibid., p. 493.

[11] Jones, *Growth recurring*.

[12] Elvin, *The pattern of the Chinese past*.

[13] Sung is the Wade–Giles spelling which is equivalent to Song in modern Pinyin spelling.

[14] Needham, *Science and civilization*, vol. 1, p. 134.

[15] Jin et al., 'The structure of science', pp. 9–10.

[16] Ibid; Liu, *China turning inward*.

[17] Ibid.

[18] Su and Liu, *Shiyi shiji zhongguo de kexue*, pp. 256–65.

Wang constructs the introspection indices of Neo-Confucianism by using the data of chastity in the Ming Dynasty and demonstrates that introspection hindered the development of science and technology in the Qing Dynasty.[19]

Contrariwise, there was no lack of scholars who demonstrated that Confucianism contained factors that had positive impact on the development of science and technology. For instance, Chan asserts that Confucius himself was not averse to the acquisition of natural knowledge, which is supported by a number of passages in The Analects, namely 'Get largely acquainted with names of birds, beasts, and plants; Comprehensive investigation; Must not interfere with the seasons of husbandry'.[20] Equally significant in Confucian education are the Six Arts of rites, music, archery, charioteering, history, and mathematics. Yet Confucianism did not extend its focus from ethics to science after its monopoly was established during the Han Dynasty until the rise of Neo-Confucianism in the Song Dynasty. As Needham succinctly summarized, 'The Neo-Confucians arrived at what was essentially an organic view of the universe … This was a world-outlook consonant with science indeed'.[21] Although Needham argues that Confucian pursuit of the sublimation of ethics had impeded science, it is clear that he does not dispute that Neo-Confucianism actually contains the seeds of natural science throughout the Song period. A case study shows that Song Confucians generally valued natural science, and the Neo-Confucian spirit characterized by benefitting society (*jishi*), broad learning, scepticism, and pursuit of principle (*li*) had a positive impact on scientific research.[22]

The main pitfall of 'conflict thesis' on the relationship between Neo-Confucianism and science is the use of 'Introspection' as the exclusive meaning of the Neo-Confucian spirit. It should be recognized that the Neo-Confucian spirit also includes benefitting society (*jishi*), broad learning, scepticism, and pursuit of principle,[23] and is not confined only to introspection or moral perfection. Indeed, Song Neo-Confucians conducted exhaustive research on nature and the universe to achieve the understanding of principles, leading to numerous scientific and technological works on medicine, magnetic compasses, fossils, mathematics, geography, cartography, etc., composed by the Confucian scholars during the Song dynasty.[24]

In addition, it is important to note the relationship between *gewu qiongli* (the investigation of things and fathoming of principles), one of the core concepts of Neo-Confucianism, and science. Some studies tackle the issue from the perspective of separating science from morality, arguing that *gewu qiongli* is solely concerned with Confucian self-cultivation theory and is unrelated to science.[25] However, Hsu argues that this separation misrepresented the genuine underlying connotations of the *wu* (things) and *li* (principles) as the Neo-Confucians manifested since moral ethics is inextricably linked to the mastery of natural knowledge.[26] Indeed, in accordance with the *jinshi*, all Confucian literati were implicitly obligated to study natural sciences such as cosmology, hydraulics, and medicine, among others. In the late Ming dynasty, the Jesuits, led by Matteo Ricci (1552–1610), not only imparted Western learning, but also legitimated it as *gezhi xue*, indicating

[19] Wang, '*Zhongguo shiwu zhi shijiu shiji keji tingzhi*'.

[20] Ibid., pp. 317–319.

[21] Ibid., pp. 412.

[22] Yue, *Songdai de ruxue yu kexue*.

[23] Ibid., pp. 116–74.

[24] Ibid., pp. 493–5.

[25] Lao, *Xinbian zhongguo zhexue shi*; Bodde, *Chinese thought, society and science*.

[26] Hsu, 'Ziran zhishi ruxue hua'.

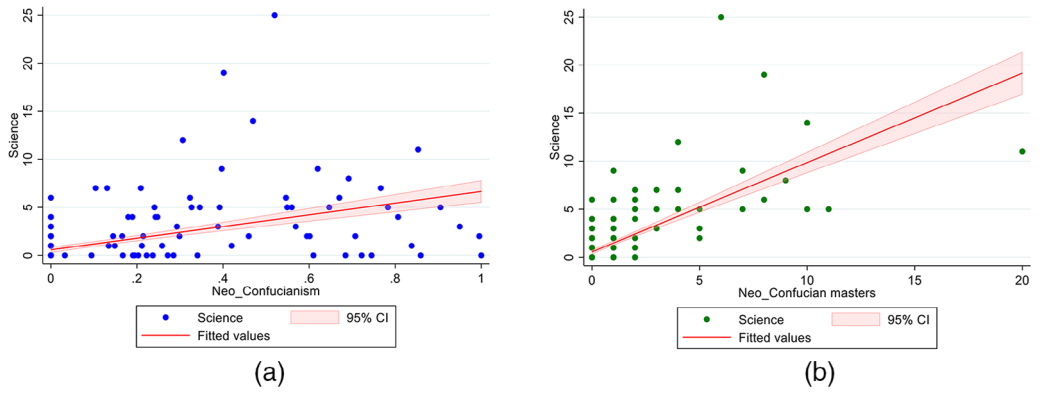

FIGURE 1 (a) Scientific advancement and Neo-Confucian spirit; (b) scientific advancement and prominent Neo-Confucians. *Source*: see table 1.
[Colour figure can be viewed at wileyonlinelibrary.com]

that the *gewu qiongli* was genuinely connected to Western learning. It was not until the beginning of the twentieth century that it was replaced by the term 'science', introduced from Japan.[27]

To examine the influence of the rise of Neo-Confucianism on the development of science and technology, we employ the text analysis method that has been widely used in recent economics literature[28] to construct the Neo-Confucian spirit indices, that is, pursuit of principle (*li*), broad learning, and scepticism[29] on the basis of Song Confucian works recorded in the *Records of Song and Yuan scholarship* (*Song Yuan xue an*)[30] and measure the scientific and technological production by the stock of technological and scientific works. Figure 1A illustrates a strikingly significant association between Neo-Confucianism measured by the Neo-Confucian spirit (which will be elaborated in detail below) and the advancements of scientific discoveries and technological breakthroughs during the Song times. Figure 1B shows a similar positive correlation between the number of Neo-Confucian masters and scientific and technological output at the prefecture level. This panel of the 'barebone' figures, without controlling any other variables, seem to strongly support Needham's assertion that the accomplishments of medieval Chinese science and technology can be ascribed, at least in part, to the influence of Neo-Confucian worldviews. The baseline ordinary least squares (OLS) results then indicate that the Neo-Confucian spirit had a positive effect on the development of science and technology in the Song Dynasty.

To address concerns of endogeneity, we use the war frequency from the late Tang Dynasty to the end of the Five Dynasties and Ten States (859–959) as the instrumental variable of Neo-Confucianism. The two-stage least squares (2SLS) regressions support the claim that Neo-Confucian spirit was conducive to scientific and technological production in the Song Dynasty. Moreover, the results remain robust against the replacement of scientific and technological works by the number of scientific and technological figures, expansion of the Neo-Confucian spirit lexicon, and regressions in grid.

[27] Ma, 'Gewu zhizhi'.

[28] For example, Baker et al., 'Measuring economic policy uncertainty'; Gentzkow et al., 'Text as Data'; Giorcelli et al., 'How does scientific progress'.

[29] Qi, *Songxue de fazhan he yanbian*, pp. 8–16; Yue, *Songdai de ruxue yu kexue*, pp. 171–4.

[30] Huang and Quan, *Song Yuan xue an*.

Finally, we examine the role of Confucian academies in the propagation of Neo-Confucian spirit. The mechanism research indicates that the vigorous expansion of the Confucian academies served as a channel through which the booming Neo-Confucian spirit affected scientific and technological output in the Song Dynasty.

Note that while this paper shows how Song Neo-Confucians aided in the advancement of science in medieval China, it does not make the assertion that Song Neo-Confucianism was a driving force behind the rise of modern science in China in later periods. The reason is that both Neo-Confucianism and science had undergone substantial transformations from the Middle Ages to modern times. On the one hand, as the ruling state ideology, Neo-Confucianism gradually lost the vigour of its proactive role over societal development since the Ming dynasty and was reduced to the emphasis on Confucian moral codes. Its de facto influence on intellectuals waned to the confines of Neo-Confucians' exegesis of the Confucian canon for the purposes of imperial examinations. On the other hand, the modern Baconian mathematical and experimental science, as a result of science revolution, was fundamentally distinct from the Aristotelian medieval science. Thus, our thesis is only confined to the Song time and not intended to offer corollaries for later dynasties.

Our study contributes to a growing literature examining how religion affects scientific output and economic growth.[31] In particular, there is a lack of quantified causal analysis in the cultural interpretation of China's historical achievements in science and technology during medieval times. Our study fills this gap by meticulous construction of Neo-Confucian spirit indices and a rigorous empirical analysis. More broadly, our paper also extends the literature on the role of Confucian culture in economic performance.[32]

In addition, our paper complements the comparative study of scientific development. Mokyr posits a hypothesis of the 'Marketplace of Ideas',[33] which attributes the backwardness of Chinese science to the unified nature of the empire throughout most of its history. The counterexample is Europe, whose divided and united nature undermined the suppression of new ideas and created a wide market for them, helped precipitate scientific knowledge, and finally led to the Industrial Revolution.[34] However, Mokyr's argument fails to explain the rise of science and technology in the Song time as a unified empire, which allegedly gave its intellectuals little incentive to innovate. By contrast, the current study fills this void by proposing a cultural interpretation of the development of science and technology.

The remainder of this article proceeds as follows. Section I articulates the historical background of Neo-Confucianism, with a focus on the logical relationship between Neo-Confucianism and science. Section II introduces the data. Section III reports and explains the main empirical results.

[31] For example, Ibid.; Bénabou et al., 'Forbidden fruits'; Mokyr, 'The economics of being Jewish'; Bai and Kung, 'Diffusing knowledge'; Squicciarini, 'Devotion and development'.

[32] For example, Weber, *The religion of China*; Kung and Ma, 'Can cultural norms'; Chen et al., 'Banking on the Confucian Clan'.

[33] Mokyr regards the 'Marketplace of Ideas' as a virtual marketplace where various ideas are exchanged. The suppliers of ideas (scientists) generate ideas and try to persuade the buyers of ideas to accept them in return. The demanders choose to adopt an idea or a new technology to maximize their utilities. The output of 'ideas' in markets is ultimately determined by both supply and demand (Ibid.).

[34] On the one hand, Europe is 'divided', with many small states, which reduces the oppression of intellectuals by a single regime and increases their incentives to create knowledge. On the other hand, Europe is 'unified' in that the close links between small states and the development of postal systems provided conditions for the repeated exchange of knowledge and science.

Section IV reports the robustness checks and endogeneity. Section V shows the role of Confucian academies in the propagation of Neo-Confucian spirit. Section VI offers a conclusion.

I | HISTORICAL BACKGROUND

The rise of Neo-Confucianism marks a distinct era in the history of Chinese philosophy, and the reasons for its emergence can be attributed to multiple aspects. The first is reflected through the frequent peasant rebellions and warlord wars from the late Tang Dynasty to the Five Dynasties and Ten States (907–59 A.D.).[35] The Song Neo-Confucians attributed the war and turmoil to the loss of the Confucian tradition and intended to restore a moral-based social order by developing a new philosophical framework. The second is influenced by the trend of 'doubting the classics' advocated by Ouyang Xiu (1007–72 A.D.). Unlike the Confucian scholars during the Han and Tang Dynasties, who were engaged in the mere collecting of and commenting on the classics, the Song Neo-Confucians were devoted to free and creative interpretations of ethical and spiritual values found in the traditional Confucian philosophy, which are regarded as a transition from a philological (*xungu*) method to a moralistic (*yili*) one. The third cause is to cope with the challenges of Buddhism and Taoism. To defend the orthodox status of Confucianism in state ideology, the Song Neo-Confucians excluded theistic religions from the ideological competition for state endorsement on the one hand, and restored Confucianism with a new philosophical foundation by embracing some Buddhist and Daoist notions on the other. In Appendix 1 we provide a more detailed background on the rise of Song Neo-Confucianism.

The implications of the Neo-Confucian spirit has already attracted the attention of relevant literature. When discussing the formation of Neo-Confucianism, Qi sums up five characteristics: doubting the Classics, distrusting Han dynasty scholars' commentaries, pioneering the study of moral principles (*yili*), stressing practicality, and pursuing the way of inner sageliness (*neisheng*) and outer kingliness (*waiwang*).[36] Sung divides the Neo-Confucian spirit into four aspects: broad learning and astute enquiry, proper cultivation of mind and body, appropriate social ethics and moral code, and good statecraft and administration.[37] On the basis of the foundation of predecessors, Yue summarizes the Neo-Confucian spirit, which is defined by benefitting society (*jishi*), broad learning, scepticism, and pursuit of principle (*li*).[38] Although the Neo-Confucian spirit gradually formed in the academic research of Song Confucians, it also exerted a subtle influence on other fields including science and technology. We focus on the spiritual aspects of Neo-Confucian that are most likely to be associated with the development of science and technology, namely, Yue's classification, and the specific analysis is as follows.

The spirit of benefitting society (*jishi*) can be presented with Fan Zhongyan's famous phrase 'Be concerned about the affairs of state before others, and enjoy comfort after others'. Due to its military incompetence, the Song Dynasty was constantly facing threats from other ethnic regimes over three centuries of its existence. The acute ethnic confrontations that the Song Neo-Confucians experienced made them deeply concerned about the fate of the empire. Similar to the 'Bacon principle' of the Age of Enlightenment, which advocates that the path of scientific

[35] Han, *Zhongguo ruxue shi: Song Yuan juan*.

[36] Ibid., pp. 8–16.

[37] Sung, 'Songdai xueshu'.

[38] Ibid., pp. 116–174.

enquiry should be pragmatic, Song Neo-Confucians investigated a variety of practical issues to serve the requirements of the state and benefit its people. In addition to their knowledge of Confucian Classics, the majority of Song Confucians excelled in the field of science and technology. For instance, Su Shi (1037–1101) was not only well-versed in Confucian classics, but also interested in nature and medicine.[39] There were numerous Confucian physicians (*ruyi*), such as Tang Shengwei (1086–1136 A.D.), Zhang Gao, etc., who regarded medicine as the profession that Confucian scholars should engage in to achieve their lofty ideal of benefitting the people. Liu Qingzhi (1133–89 A.D.), a notable Neo-Confucian during the Southern Song period, devoted himself to the study of agronomy and geography, and wrote *The Book of Agriculture* (*Nong shu*) and *The Pictorial Classics of Hengzhou* (*Hengzhou tujing*). In addition, Zheng Qiao (1104–62) also exhibited the broad learning spirit common to Song Neo-Confucians.[40] He not only had high accomplishments in *the Book of Songs* (*shijing*), but also contributed to biology with his work *The investigation of insect and vegetation* (*Kunchong caomu lue*). The cases of Song Neo-Confucians engaged in scientific and technological activities are presented in appendix table A1. It should be noted that the fact that medieval Chinese sciences were dominated by geography, Chinese herbal medicine, and agronomy, characterized by empiricism, was comparable to that of medieval European sciences, which included the study of nature, cosmology, and pathology.

The Neo-Confucian sceptical spirit is reflected in the questioning of the veracity of Classics written after Confucius and Mencius as well as in the mistrust of commentaries from the Han through the Tang dynasties. The scepticism that prevailed in the Song Dynasty is similar to the cultural concepts shaped by the Age of Enlightenment: All knowledge and ideas, whether old or new, can be challenged and criticized without ultimate authority.[41] Even while the Neo-Confucian legacy of scepticism was viewed as a form of positive scepticism, lacking stringent demand for the exactness and objectivity of knowledge,[42] it did not prevent Neo-Confucians from exploring the external world with a sceptical mindset. According to Needham, 'the whole of the Sung Neo-Confucian school had an intensely naturalistic and sceptical tendency'.[43] In contrast to Confucians of other dynasties, Song Neo-Confucians did not assume that ancient sages' achievements in natural knowledge were flawless; rather, they viewed science (the study of natural knowledge) as a dynamic and expanding subject. In his study of cartography and geography, Zhu Xi found those who passively followed Mencius' incorrect interpretation of the *Yu gong* chapter to be laughable. This rather accommodating attitude of the Neo-Confucians towards science allowed for the development of science and technology during the Song dynasty. Shen Kuo (1031–95), whom Needham hailed as 'the landmark in the history of Chinese science', exhibited scientific scepticism that was based on his own observations and experiments as opposed to mindlessly copying

[39] *Su Shi wenji* contains a chapter on vegetation and diet which describes a wealth of scientific and technological knowledge (Su, *Su Shi wenji*, *juan* 73). In additional, Su Shi had a more in-depth study of medicine, which is reflected in his medical books such as *Su Shen liangfang*.

[40] Zheng Qiao was involved in rites and music (*li yue*), literature, astronomy, geography, insects, and vegetation (Tuotuo, *Song shi, juan* 436, biography of Zheng Qiao).

[41] Mokyr, 'The intellectual origins', p. 341.

[42] On the contrary, the West experienced negative scepticism that developed into a weapon against metaphysical thinking and an effective tool to pursue truth through Kant's transformation, and finally achieved compatibility with modern science (Cheng, *New dimensions of Confucian*, pp.108–28).

[43] Ibid., p. 338.

his predecessors.[44] It is worth mentioning that his scientific scepticism was influenced to some extent by the general trend of 'doubting the Classics' initiated by Ouyang Xiu, as evidenced by his praise of Ouyang Xiu's efforts to change the trend of imitation in his scientific masterpiece *The dream pool essays* (*Mengxi bitan*).[45]

The spirit of pursuit of principle (*li*) was a landmark symbol of the Neo-Confucianism and became a prevailing mentality in the Song Dynasty. Cheng Hao and Cheng Yi established the theory of Neo-Confucianism with 'heavenly principle' (*tian li*), that is, the coherence of the universe as a whole and all things within it. *Gewu qiongli* (the investigation of things and fathoming of principles) must be known to attain comprehension of 'heavenly principle'. Moreover, the scope of *gewu* (investigating things) is infinite and all inclusive, including natural things. In appendix 2, we list the contributions of Zhang Zai, Zhou Dunyi, and Shao Yong, three Song Neo-Confucian masters, to astronomy.

Although it should be noted that Song Neo-Confucians' teaching of *gewu* was ultimately for the pursuit of moral perfection and ethics rather than scientific matters, they did make some salient scientific or proto-scientific observations at a time when few intellectuals were concerned with such endeavours and the officialdom did not hold engineers or scientists in high regard.[46] For instance, Zhu Xi not only conducted extensive research on the structure and improvement of the 'armillary sphere', a measuring instrument, but also used it to observe the position of the North Star, trying to speculate on the movement of the Earth by comparing the relationship between the height of the North Star measured in various places and the centre of the earth (*di zhong*). His scientific work, *Beichen bian*, was devoted to the study of the displacement of the North Star or the Polaris.

Indeed, the thought of *gewu* advocated by Zhu Xi includes scientific methodologies such as investigation, induction, and analogy.[47] To aid in the comprehension of nature, Neo-Confucian masters also created proto-scientific models and thought experiments. Zhu Xi discussed the difference between the orbits of the sun and the moon in his work, and then further explored the causes of the moon's changes in phases using candles and fans to simulate and experiment.[48] When explaining the formation of precipitation to one of his disciples, Zhu Xi used the rice steaming pot as an illustration.[49]

Song Neo-Confucians found that the investigation of natural things using suitable approaches, including experimental ones, outperformed traditional methods such as reading Confucian canons alone. In situations in which natural phenomena seemed to be contradictory to the Neo-Confucian ethical theory that guides the propriety and appropriateness of conduct, the Song Neo-Confucians resorted to experiments. For instance, Zhu Xi did not believe the popular notion that bamboo sprouts only grow at night, and employed experimentation to demonstrated that the contrary was true, despite his claim that the night was vital for the growth of humaneness because of its quietness.[50]

[44] For instance, Shen Kuo criticized various disadvantages of the method of the intercalary month in the lunar calendar used by predecessors in favour of a more scientific and practical calendar called 'Twelve qi calendar'.

[45] Shen, *Mengxi bitan*, *juan* 9, *renshi*.

[46] Kim, *The natural philosophy*.

[47] Li, *Zhuzi yulei*, *juan* 117.

[48] Zhu, *Zhu wengong wenji*, *juan* 45.

[49] Li, *Zhuzi yulei*, *juan* 100.

[50] Li, *Zhuzi yulei*, *juan* 138.

Thus, although one may argue that the notion of 'attaining knowledge' (*Zhizhi*) by the Neo-Confucians was intended to cultivate the mind, the Song Neo-Confucians were not bound by judgements that are prima facie in accordance with conventions and virtue and were open to a variety of tools most suitable for attaining natural knowledge. For the majority of Neo-Confucians, such as Zhu Xi, attaining knowledge is tantamount to investigating the constituent patterns and principles of natural things. Qian commented on Zhu Xi: 'with his acute observation and lively imagination, Zhu Xi's discoveries in the field of natural science are also far ahead of others in the history of science'.[51]

II | DATA

To measure scientific and technological production, we use the stock of scientific and technological works (book titles) written by Song dynasty scholars at the prefecture level, with reference to Chaney and Ma.[52] Specifically, the dataset is obtained from the *Bibliographic treatises of the Song Dynastic History* (*Song shi yi wen zhi*).[53] The collection is compiled with the 'quartering' of historiographical bibliography, in which the number of ancient Chinese traditional scientific and technological categories including astronomy, calendar, agronomy, medicine, and geography can be clearly identified.[54] Since only the title and author's name were recorded in the collection, we identified and collated the author's place(s) of residence and the approximate period of publication on the basis of the reference provided by 'Baidu Baike' (a Chinese counterpart of Wikipedia) and China Biographical Database (CBDB).[55] For books whose precise dates of first publication were unrecorded, we impute each of them according to the year of the author's age at midlife.[56] On the basis of the authors' places of residence and period of publication, we count the number of book titles by prefecture and year. Excluding those whose biographies are unknown, 339 scientific and technological works of the Song Dynasty are finally obtained, including 170 on geography, 88 on medicine, 38 on agronomy, 25 on calendar, 10 on astronomy, and 8 on mathematics. The spatial distribution of scientific and technological works in the Song dynasty is shown in figure 2.

It should be highlighted that the fact that medieval Chinese sciences were dominated by geography, Chinese herbal medicine, and agronomy, characterized by empiricism, was comparable to that of medieval European sciences, which included the study of nature, cosmology, and pathology.[57] The bulk of medieval manuscripts persuasively demonstrate that modern science was not

[51] Qian, *Zhuzi xue tigang*, p. 122.

[52] Chaney ('Religion and the rise and fall') constructed a dataset by including every book from Harvard's collection of surviving books written by authors with an Islamic-sounding name. Ma used the vector map of China's prefecture-level administrative divisions during the period of Ming-Qing obtained from 'Harvard China Historical Geographic Information System (CHGIS, 2016)' (Ibid.). The prefecture-level map of the Song dynasty used in our paper is currently only available from 'Hartwell China Historical GIS'. https://doi.org/10.7910/DVN/29302

[53] Tuo, *Song shi yi wen zhi*, in Wang and Liu eds., *Ershiwu shi yi wen jing ji zhi kaobu cuibian*, vol. 20.

[54] Zha, 'Dui ershiwu shi de "yiwenzhi" "jingjizhi"', p. 72. The 'quartering' includes Classics (*Jing*), Histories (*Shi*), Masters (*Zi*), and Collections (*Ji*). Among them, astronomy, calendar, agronomy, and medicine are included in the Masters (*Zi*), and geography is included in the Histories (*Shi*).

[55] Harvard University, Academia Sinica, and Peking University, *China Biographical Database Project*.

[56] The average age of all the authors in our sample at midlife was around 33 years. This was equivalent to the average age of literati who had obtained the provincial-level (*juren*) or national-level (*jinshi*) degrees in the imperial examinations (Elman, *A cultural history*), which tended to be the highpoint of scholarly activity for literati (Ibid., p. 13.).

[57] Lindberg, *The beginnings of Western science*.

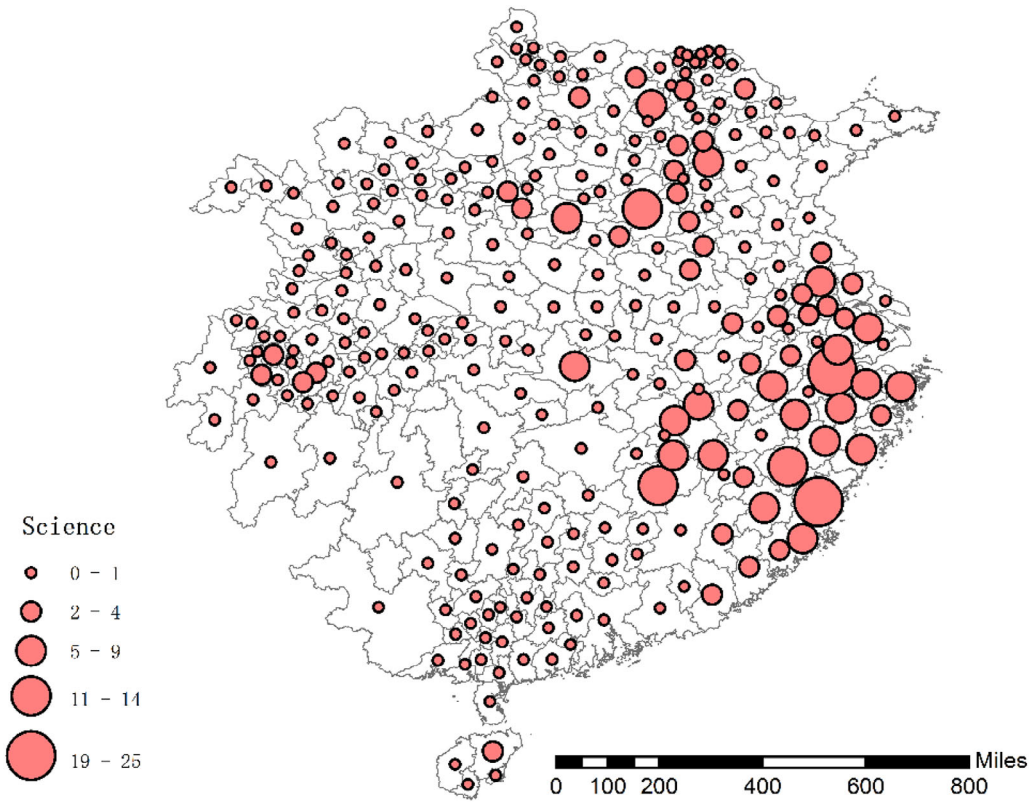

FIGURE 2 Spatial distribution of scientific and technological works in the Song dynasty. *Source*:Hartwell, *Hartwell China Historical GIS*.
[Colour figure can be viewed at wileyonlinelibrary.com]

a creation of the seventeenth century, indicating that early European modern scientists had intellectual forebears that may be traced to medieval times.[58] Beyond the purview of the current paper are the divergent pathways taken by China and Europe at the dawn of modern science that are relevant to the discussions of the Great Divergence. It is thought that the stagnation of Chinese research since the fall of the Song Dynasty is deeply rooted. Likewise, the causes for the rise of modern science in Europe during the seventeenth century were in sharp contrast to China, but equally complicated.[59]

Our key explanatory variable of interest is the Neo-Confucian spirit. The data of *jinshi*, chaste women (*lienü*), and Confucian temples are frequently used in existing studies to gauge the

[58] Duhem, *Le système du monde*.

[59] The tension between the Aristotelian–Thomistic natural philosophy and the spirit of modern mathematical and experimental science was originated by Aristotle, whose definition of science was based on pure rationality (Tanzella-Nitti et al., 'Religion and science'). This tension led to the triumph of experimental science with a solid rationalism foundation. By comparison, the lack of a natural philosophy such as Aristotelian in the Axial Age and the absence of a dominant transcendental religion later resulted in an empirical development model of Chinese science from antiquity to pre-modern times. However, the linear growth paradigm of Chinese science is precisely what prevented modern science from emerging from China.

strength of Neo-Confucian culture,[60] but these measures have significant shortcomings when it comes to accurately capturing the Neo-Confucian spirit during the Song Dynasty. The specific reasons are as follows.

From the 1070s or the mid-Northern Song dynasty until its abolition in the 1790s, there existed an imperial examination system labelled '*zhuanjing qushi*', where in writing the exams, candidates were free to choose one specific Confucian classic out of the Five Confucian Classics, that is, *The Book of Songs* (*Shijing*), *The Book of History* (*Shujing*), *The Classic of Rites* (*Liji*), *The Book of Changes* (*Yijing*), and *The Spring and Autumn Annals* (*Chunqiu*). Using local gazetteers and archives, Ding demonstrates that the choices of the Confucian classics varied across localities and changed over time.[61] In particular, in Huizhou prefecture, *The Spring and Autumn Annals* was the most frequently chosen classic by the earned *jinshi* in Southern Song dynasty. However, as shown in a discussion between Zhu Xi and his disciple on this matter, Zhu Xi expressed deep concerns over the popularity of *The Spring and Autumn Annals*, as it may impede the genuine understanding of the principles of righteousness. Indeed, the fact that *The Spring and Autumn Annals* was the favourite choice among young Confucian students, together with its lack of embedded Neo-Confucian spirit compared with *The Book of Documents* (*Shangshu*), made the earned *jinshi* based on '*zhuanjing qushi*' a poor proxy to cross sectional measure of Neo-Confucian spirit.

Although it is widely accepted that Zhu Xi's ethical theory of 'upholding heavenly principle and annihilating human desire' contributed to the prevalence of chaste women, Song Confucians' views on chastity acts were not uniform. For instance, Cheng Yi insisted that nothing was more important to a woman than preserving chastity after the death of her husband, while Su Shi valued women with both virtue and talent, namely '*xian yuan*'. This discrepancy stems from their diverging understandings of human nature (*xing*). Cheng Yi equated human nature with heavenly principle (*xing ji li*), thereby accepting the Mencian doctrine that human nature is inherently benevolent. Evil arises from ex post societal conditions and is associated with human desire, whereas the eradication of human desire is required for the return of nature. In contrast, Su Shi maintained that human nature is neither good nor evil and should be respected and obeyed, and that it is inappropriate to strangle human needs and feelings according to moral dogmas imposed by an authority.[62] The *Shi Shuo* imitations written by Su Shi's disciples authentically present the diversity and nuance of human nature, amongst which the chapter '*xian yuan*' honoured women who possessed both moral fortitude and literary talent, and turns away the single moral standard.[63] The assessment of chaste women as a tragedy by Song Confucians such as Su Shi and his followers, who were dissatisfied with the ethics of annihilating human desire, suggested that the use of chaste women fails to convey the entirety of Neo-Confucian spirit. In addition, only 38 instances of chaste women are recorded in the *Lienü biography of Song history*, indicating that chastity acts in the Song Dynasty were rare. Not until the Ming and Qing Dynasties did the number of chaste women expand exponentially, as the imperial court codified chastity acts.[64]

The use of Confucian temples as a proxy of Neo-Confucian value in the Song dynasty is also controversial. This is because the construction of Confucian temples during the Song Dynasty was at least partially driven by the booming demand of education. Under the principle of honouring

[60] Ibid.

[61] Ding, 'Huizhou keju dili yanbian'.

[62] Kong, 'Lun Su Shi yu Cheng Yi'.

[63] Qian, 'Lienü versus xianyuan'.

[64] Theiss, *Disgraceful matters*.

Confucius and stressing education, the emperors of the Northern Song Dynasty undertook three programmes to promote education. The local government refurbished Confucian temples one by one and emphasized 'the integration system of Confucian temples and learning' (*miaoxue zhi*), in opposition to the Tang Dynasty's practice of prioritizing sacrifice and disregarding education in Confucian temples.[65] However, the exegeses of Song Neo-Confucians were not included in the official curriculum. It was not until the end of the Southern Song Dynasty that the emperor Li Zong (1226–64 A.D.) officially enshrined the masters of Neo-Confucianism – Zhu Xi, Cheng Hao, Cheng Yi, Zhou Dunyi, and Zhang Zai – in the Confucian temple. In other words, the Confucian temple is a poor proxy for the so-called Neo-Confucian spirit in the context of the Song Dynasty. Moreover, there are very few surviving Confucian temples from the Northern Song dynasty or earlier.[66] In 1127, the Jurchens sacked *Bianliang* (the capital of the Northern Song dynasty) and marked the end of the Northern Song dynasty. The early Jurchen rulers who occupied northern China were vehemently hostile to Confucian temples because Confucius's scorn for barbarians was not conducive to their establishment of prestige and dominance in the former Song Dynasty territory.[67] As a consequence, Confucian temples in the northern provinces were entirely destroyed at an early point by the Jurchen regime.

For the aforementioned reasons, we employ the digital humanistic method proposed by Li and Qiu et al. in the study of ideological history.[68] It implements text analysis on an enormous amount of historical materials and uses the frequency of corresponding keyword clusters calculated by computer tools to study the history of thoughts. The specific construction process of Neo-Confucianism spirit indices is as follows.

The first step is to select the text object. On the basis of the Neo-Confucian's biography recorded in the *Records of Song and Yuan scholarship* (*Song Yuan xue an*),[69] we screen out those who have surviving works or opinions. To address the issue of reverse causality, samples of Neo-Confucians born later than the publication year of scientific works in the same prefecture are eliminated. We obtain a total of 193 Song Neo-Confucians, including Hu Yuan, the 'Five Masters of the Northern Song', Zhu Xi, and so on.

The second step is to preprocess the text. The full text or remarks of the works are imported into Python, and the word segmentation is performed with the 'jiayan module'[70]. The words without practical analytical meaning, such as title number and interjection, are then deleted by using 'Stop Vocabulary Table' and 'Ancient Chinese Function Words Lexicon'.[71]

The final step is to generate the frequency of keywords. Firstly, 10 per cent of the representative texts from the *Records of Song and Yuan scholarship* (*Song and Yuan xue an*) is chosen for manual reading. The outcome of the reading is the construction of a list of words or phrases that underscore the aforementioned essential Neo-Confucian values, that is, broad learning, scepticism, and

[65] Fan, *Zhongguo kongmiao*, p. 31.

[66] Ibid.

[67] Shen, 'Difang kongmiao'.

[68] Li, 'Lianghan shehui guannian'; Qiu et al., 'Zhongguo jindai pingdeng guannian'.

[69] *Song Yuan xue an* summarize the scholarship thought and representative figures of the Song, Jin, and Yuan dynasties over 400 years, extract their academic gist, reveal their sources of teachers and successors, and provide the previous comments. The text of the book is 100 volumes, and each study plan generally consists of a scholarship table, preface, biographical sketches, ideological data, and appendix.

[70] A kind of natural language processing (NLP) toolkit focuses on the processing of ancient Chinese, supporting textual lexicon synthesis, word segmentation, pos tagging, sentence breaking, and punctuation.

[71] Ibid., p. 538.

pursuit of principles (*li*).[72] For instance, 'heavenly principle' (*tian li*), 'fathom the principles' (*qiong li*), 'everything' (*wan wu*), 'nature', 'doubt', etc., are used as seed lexicon (see table A2 of appendix). Given that the expresser frequently uses multiple words with similar semantics to explain the same concept, we then use the Word2Vec machine learning method developed by Mikolov to train and find the synonyms of seed words to expand the lexicon from the entire text.[73] Specifically, we use the Continuous Bag of Words (CBOW) model in Word2Vec to train the corpus of Song Confucian works, and the model is as follows:

$$\max \sum_{w \in C} \log p(w|Context(w)) \tag{1}$$

where C represents corpus, w stands for center word, and $Context\,(w)$ indicates the context of the central word. The basic idea of the CBOW model is to predict the occurrence probability of the current word based on context by maximizing the above objective function, and then to obtain the corresponding word vector of the central word. Finally, the similar words of the center words can be obtained by calculating the vector similarity.

The expanded lexicon is automatically generated by the CBOW model to avoid the subjectivity of artificially defined vocabularies. Eventually, we ended up with a 'Neo-Confucian spirit lexicon' with 133 keywords. The percentage of keyword frequency in the total word frequency of the work is used to measure the Neo-Confucian spirit. The spatial distribution of Neo-Confucian spirit is shown in figure 3.

The first category of control variables is a vector of human capital, including *writing _ intensity* and *jinshi _ density*. There is no doubt that human capital is one of the important factors affecting scientific and technological production, but it is often intertwined with the Neo-Confucian spirit, which leads to the overestimation of the influence of Confucian culture if it is not separately controlled for. To obtain a clean measure of human capital (excluding Confucian culture), we first select all books written in the Song Dynasty from *The Complete library in four treasures* (*Siku quanshu*)[74] and its continuation, the *Xuxiu Siku quanshu*, and match them with the birthplaces of the authors. A total of 1052 books are then obtained after excluding Confucian works,[75] and the number of books per hundred households (*writing _ intensity*) is used as a proxy variable for human capital. As previously mentioned, Imperial China based its education system on the civil service examination, while the number of *jinshi* at the higher level of each prefecture can be a proxy for educational level. The number of *jinshi* per hundred households (*hu*) can serve as a measure of human capital (*jinshi_density*).[76]

[72] Ibid., pp. 8–16; Yue, Ibid., pp. 171–4.

[73] Mikolov et al., 'Distributed representations of words and phrases'. The Word2Vec is based on the neural network model, which converts words into multi-dimensional vectors according to contextual semantic information, and obtains semantic similarity between words by calculating the similarity between vectors; Bengio et al., 'Distributed representations of words and phrases and their compositionality'.

[74] *The Siku quanshu*, which was compiled on the order of Emperor Qianlong (1736–96 A.D.) in the Qing Dynasty, was the largest collection of books in Chinese history, with 3503 works, 79 337 volumes, and about 997 million words; Ji, *Siku quanshu*; Compilation Committee of Continued Revision of the Siku quanshu, *Xuxiu Siku quanshu*. The complete catalogue was divided into four sections: Classics (*Jing*), Histories (*Shi*), Masters (*Zi*), and Collections (*Ji*).

[75] Confucian works are contained in the Confucian Category (*Rujia lei*) of the section of Masters (*Zi*), and the section of Classics (*Jing*).

[76] The *jinshi* data are obtained from Chaffee, *The thorny gates of learning in Sung China*.

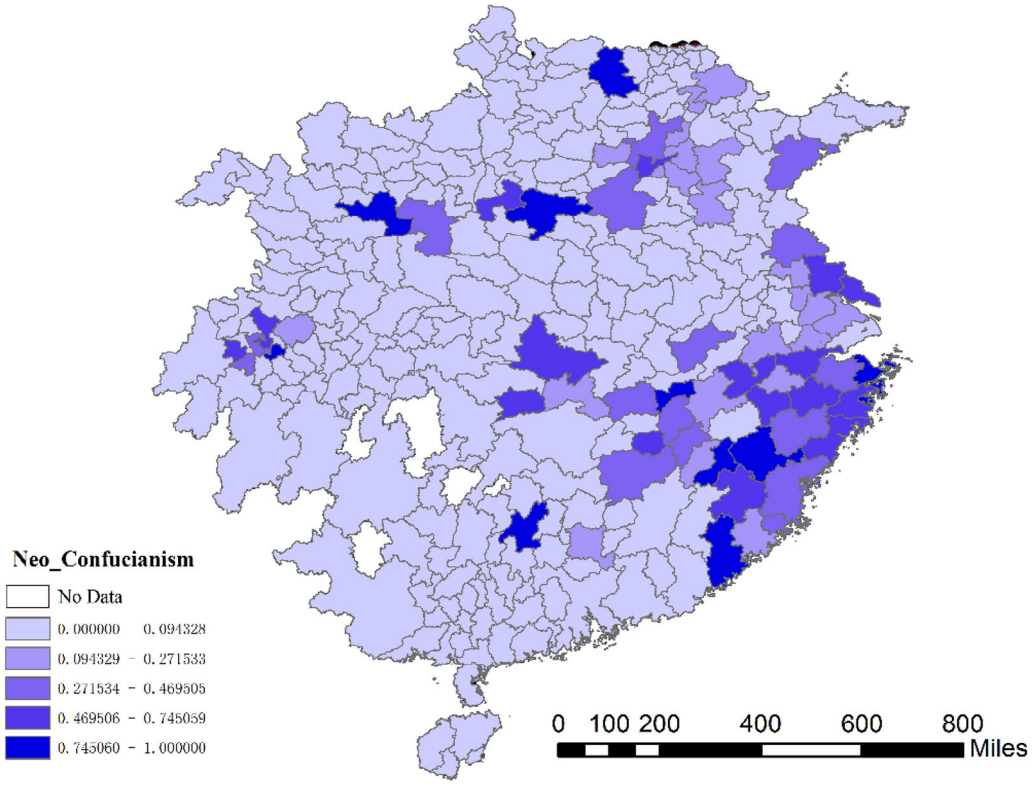

FIGURE 3 Spatial distribution of Neo-Confucian spirit in the Song Dynasty. *Source*: Hartwell, *Hartwell China Historical GIS*.
[Colour figure can be viewed at wileyonlinelibrary.com]

The second category includes the economic control variables, because scientific and technological production is likely to be higher in prosperous prefectures. In the absence of reliable gross domestic product (GDP) figures, the population is a proxy for historical economic prosperity.[77] We use historical statistics of the numbers of households (*hu*) at the prefecture level in 1078 to generate the number of households per square kilometre (*pop_density*) as a measure of population density.[78] Commercial prosperity is measured by the natural logarithm of the commercial tax. The data are collected from *Song hui yao ji gao*, which provided the prefectural commercial tax in 1077.[79] In addition, the scale and scope of overseas trade and long-distance trade in the Song Dynasty were far greater than those in the Tang Dynasty.[80] A wide variety of imports might impact the domestic commodity market and the development of science. To accommodate the possible

[77] Acemoglu et al., 'Reversal of fortune'.

[78] The data of households in 1078 are obtained from Liang, *Lidai hukou, tudi, tianfu tongji*, pp. 199–209.

[79] Liu et al., eds., *Song hui yao ji gao*. Since the commercial tax of the southwest province is measured in iron coins, and other areas are measured in copper coins, it is necessary to convert the commercial tax of the southwest province according to the ratio of iron coins to copper coins at 2:1; Guo, 'Tieqian yu Songdai shangshui'.

[80] Liu, 'The making of a fiscal state'.

impact of foreign trade, the distance to the trade ports (*dist_trade port*) for a prefecture's centroid are controlled and calculated by ArcGIS. [81]

Last but not least, several geographic factors may be correlated with scientific and technological production. Given that the Song dynasty was an agriculture-dominated society, the abundance and surplus of agriculture may contribute to scientific and technological development. We use a prefecture's suitability for planting the prevailing major staple grains (wheat and rice) to measure its potential agricultural productivity.[82] Moreover, ruggedness and latitude are also controlled as geographic factors. Ruggedness is calculated by using GTOPO30 global surface elevation data according to the calculation method of Riley et al.[83] The descriptive statistics of all the variables are reported in table 1.

III | MAIN RESULTS

To formally examine the effect of the rise of Neo-Confucianism on the development of science in the Song Dynasty, we begin with our baseline estimation of the following specification:

$$Science_i = \alpha_1 + \beta_1 Neo\_Confucianism_i + \theta_1 X_i^c + \delta_p + \varepsilon_{1i} \quad (2)$$

where i indexes the 287 prefectures; the dependent variable $Science_i$ represents the stock of scientific and technological works at the prefecture level; the key explanatory variable $Neo\_Confucianism_i$ is determined by using principal component analysis and standardization of the three characteristic spirits, including the pursuit of principle (*li*), broad learning, and scepticism; X_i^c represents a vector of prefecture-level control variables as introduced in section II; δ_p is the provincial dummies controlling for province specific effects;[84] and ε_i is the error term.

The baseline results on specification (2) are reported in table 2. When only the province-fixed effect is controlled without adding other control variables, Neo-Confucian spirit had a significant and positive effect on scientific and technological works, as shown in column (1). We then incorporate *jinshi_density*, *writing_density*, and *population_density*, respectively, into our regressions to clear the concerns that our results were driven by other confounders posing as Neo-Confucian spirit. Observe from columns (4) and (5) that *writing_density* is never significant in explaining science, and while *Jinshi_density* and *population_density* are significant and positive when separately regressed [columns (2) and (6)], their statistical significance and magnitude decline when Neo-Confucian spirit is added [see columns (3) and (7)], and the statistical significance of *writing_density* and *population_density* is completely lost when all control variables are in place [column (8)]. More importantly, in all regressions, the explanatory power of the Neo-Confucian spirit remains strong and is quite immune to the variations of control variables. Thus, the results from table 2 indicate that our main argument is not overshadowed by several alternative interpretations and support the views of Needham, who claimed that the accomplishments of medieval Chinese science can be ascribed, at least in part, to the influence of Neo-Confucian worldviews.

[81] The main trade ports in the Song Dynasty include Hangzhou, Mingzhou, Wenzhou, Quanzhou, Guangzhou, Chaozhou, Qinzhou, and Qiongzhou. (Huang, *Songdai haiwai maoyi*, pp. 19–25.)

[82] The data are obtained from the Food and Agriculture Organization's Global Agro-Ecological Zones (GAEZ) database.

[83] The data of GTOPO30 are from US Geological Survey; Riley et al., 'A terrain ruggedness index', p. 21.

[84] The province here, which actually refers to '*lu*' in the Song Dynasty, was an administrative unit above the level of the prefecture.

TABLE 1 Summary statistics.

Variables	Obs.	Mean	Std. dev.	Min.	Max.	Source
Science	287	1.185	2.744	0	25	1
Scientist	287	0.564	1.238	0	10	2
Neo_Confucianism	287	0.100	0.223	0	1	3
Principle (×100)	287	0.153	0.437	0	2.963	3
Broad_learning (×100)	287	0.409	1.151	0	7.783	3
Scepticism (×100)	287	0.036	0.080	0	0.568	3
Writing_intensity	287	0.005	0.015	0	0.141	4
Jinshi_density	287	0.110	0.213	0	1.495	5
Pop_density	287	7.918	7.411	0.038	63.20	6
lnctax	287	8.970	1.194	2.338	12.90	7
In (Dist_trade port)	287	6.149	1.303	0	7.346	8
Ricesuit	287	8.146	6.908	0	29.11	9
Wheatsuit	287	29.19	14.21	0.583	62.31	9
Ruggedness	287	185.0	150.4	4.650	916.5	10
Latitude	287	31.48	4.908	18.57	39.20	11
War	287	0.293	0.688	0	5	12
Academy_density(×1000)	287	0.139	0.324	0	2.062	13

Sources:
1. Tuo, *Song shi yi wen zhi*, in Wang and Liu eds., *Ershiwu shi yi wen jing ji zhi kaobu cuibian*, vol.20.
2. Li, *Zhonoguo lidai keji renwu shengzu nianbiao*, pp. 24–44.
3. Huang and Quan, *Song Yuan xue an*.
4. Ji, *Siku quanshu*. Compilation Committee of Continued Revision of the Siku quanshu, *Xuxiu Siku quanshu*.
5. Chaffee, *The thorny gates of learning in Sung China*.
6. Liang, *Lidai hukou, tudi, tianfu tongji*, pp. 199–209.
7. Liu et al., eds., *Song hui yao ji gao*.
8. Huang, *Songdai haiwai maoyi*, pp. 19–25.
9. The Food and Agriculture Organization's Global Agro-Ecological Zones (GAEZ) database.
10. U.S. Geological Survey; Riley et al., 'A Terrain Ruggedness Index'.
11. Hartwell, *Hartwell China Historical GIS*.
12. Compilation Committee of Chinese Military History, *Zhongguo lidai zhanzheng nianbiao*, pp. 505–40.
13. Bai, *Zhongguo gudai shuyuan*, pp. 4–26.

IV | ROBUSTNESS CHECKS AND ENDOGENEITY

Extending the Neo-Confucian spirit lexicon. Since the indices of Neo-Confucian spirit are generated using text analysis, we alter the building method of the 'Neo-Confucian spirit lexicon' to verify the robustness of the indices. Specifically, synonyms with a similarity greater than 0.6 to the seed words are used as keywords (the similarity between the synonyms and the seed words is 0.8 in the benchmark regression), thereby constructing the 500-word lexicon as the basis for the indices of Neo-Confucian spirit. The results with extended Neo-Confucian Lexicon show that the effect of Neo-Confucian spirit on scientific output during the Song Dynasty is robustly significant and positive in table 3, as one compares the results obtained from a more stringent lexicon (similarity of 0.8) as presented in table 2.

Replacing scientific and technological works with scientists and technologists. The number of scientific and technological talents is also a commonly used variable to measure the strength of

TABLE 2 Neo-Confucianism and science: OLS estimates.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Science							
Neo_Confucianism	2.960***		2.581***		2.914***		2.890***	2.389**
	(0.894)		(0.919)		(0.894)		(0.896)	(0.962)
Jinshi_density		3.840**	3.367*					3.286*
		(1.726)	(1.836)					(1.951)
Writing_intensity				10.904	8.062			4.153
				(7.786)	(6.200)			(5.493)
Pop_density						0.041**	0.035*	0.031
						(0.020)	(0.019)	(0.025)
lnctax								0.247**
								(0.115)
In (Dist_trade port)								−0.471
								(0.468)
Ricesuit								0.021
								(0.036)
Wheatsuit								−0.001
								(0.011)
Ruggedness								0.003*
								(0.001)
Latitude								0.167
								(0.118)
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.030	0.006	−0.486	0.619**	−0.013	−0.126	−0.650	−6.202**
	(0.400)	(0.373)	(0.436)	(0.255)	(0.398)	(0.418)	(0.554)	(3.093)
Observations	287	287	287	287	287	287	287	287
R-squared	0.487	0.488	0.517	0.450	0.488	0.454	0.492	0.555

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

science and technology. On the basis of *The chronology of birth and death of Chinese ancient scientists and technologists*, 162 scientists and technologists in the Song Dynasty are selected to replace the dependent variable.[85] In conclusion, the two sets of data complement each other, and the use of scientists and technologists provides a further test for the robustness of dependent variable. The results are consistent with the baseline results and are presented in table 4.

Regressions in grid. To avoid interference from the changes of administrative divisions in Song Dynasty, we first calculate the value of each variable in a grid cell, and then use them in the regression instead.[86] All results also point to a significantly positive effect of Neo-Confucian spirit on scientific and technological production as presented in table 5, regardless of the inclusion of control variables, which indicates that our conclusions are robust to the changes of administrative

[85] Li and Zha, *Zhonoguo lidai keji renwu shengzu nianbiao*, pp. 24–44.

[86] Nunn and Puga, 'Ruggedness'.

TABLE 3 Robustness check: extending Neo-Confucianism lexicon.

Variables	(1) Science	(2)	(3)	(4)	(5)
Neo_Confucianism_extend	3.480***	2.956***	3.428***	3.380***	2.650***
	(0.791)	(0.824)	(0.790)	(0.799)	(0.861)
Jinshi_density		3.156*			3.098
		(1.797)			(1.925)
Writing_intensity			7.430		4.118
			(5.842)		(5.491)
Pop_density				0.031	0.028
				(0.020)	(0.025)
lnctax					0.235**
					(0.109)
In (Dist_trade port)					−0.476
					(0.471)
Ricesuit					0.018
					(0.035)
Wheatsuit					−0.000
					(0.011)
Ruggedness					0.003*
					(0.001)
Latitude					0.165
					(0.115)
Province FE	Yes	Yes	Yes	Yes	Yes
Constant	−0.046	−0.498	−0.084	−0.648	−5.832*
	(0.361)	(0.431)	(0.361)	(0.524)	(3.056)
Observations	287	287	287	287	287
R-squared	0.494	0.520	0.495	0.498	0.556

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

boundaries. Nevertheless, the population, *jinshi*, and commercial tax data at the grid level, cannot be obtained due to the limitations of the data and are not presented in table 5.

Exclude the frontier areas. As a result of the low population density of the border areas, we exclude the frontier regions bordering the Liao Dynasty, the Western Xia Dynasty, the Tufan Tribes, and the Dali Dynasty to make our conclusions more convincing. Table 6 presents the main results as unchanged.

Although we have already controlled for many potential confounders in OLS, there may still be some factors that cannot be captured by the model, leading to plausible bias of the benchmark results. To deal with endogenous issues, we employ the war frequency from the late Tang Dynasty to the end of the Five Dynasties and Ten States as the instrumental variable of Neo-Confucian spirit in 2SLS regressions.[87]

[87] The data are from *Zhongguo lidai zhanzheng nianbiao*, which records the specific locations of wars from 'Qiu Fu Rebellions' (859) that started the peasant rebellions at the end of the Tang Dynasty to 'The War between the Later Zhou and

TABLE 4 Robustness check: replacing scientific works with scientists.

	(1)	(2)	(3)	(4)	(5)
Variables	**Scientist**				
Neo_Confucianism	1.760***	1.699***	1.732***	1.713***	1.511***
	(0.518)	(0.520)	(0.516)	(0.531)	(0.521)
Jinshi_density		0.541			0.479
		(0.430)			(0.437)
Writing_intensity			4.931		5.087*
			(3.338)		(2.966)
Pop_density				0.023**	0.027**
				(0.011)	(0.014)
lnctax					0.123**
					(0.053)
In (Dist_trade port)					−0.078
					(0.083)
Ricesuit					−0.007
					(0.014)
Wheatsuit					0.006
					(0.008)
Ruggedness					0.002**
					(0.001)
Latitude					0.017
					(0.048)
Province FE	Yes	Yes	Yes	Yes	Yes
Constant	0.068	−0.015	0.041	−0.387	−2.294
	(0.295)	(0.286)	(0.294)	(0.275)	(1.807)
Observations	287	287	287	287	287
R-squared	0.460	0.464	0.463	0.472	0.500

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

The political fragmentation and catastrophic upheavals of the Five Dynasty and Ten States period fostered the birth of Neo-Confucianism. Two factors contributed to the rise of Neo-Confucianism in this bellicose framework. On the one hand, literati began to introspect the lessons learned from the brutality of the wars and attributed the disorder to the loss of deep-rooted Confucian traditions. On the other hand, the imperial court's reflection on the disastrous consequences of reliance on military triggered a rectification of the state policy that accorded the literati a high degree of respect. Specifically, towards the end of the Tang dynasty, the empire was plagued by competing warlords and eventually broken into smaller parallel regimes who constantly fought each other for more than half a century. By the time the Song reunited China, the country had suffered from serious moral decline and there was an urgent need for the restoration

Liao' at the end of the Five Dynasties and Ten States. (Compilation Committee of Chinese Military History, *Zhongguo lidai zhanzheng nianbiao*, pp. 505–40.)

TABLE 5 Robustness check: regressions in grid.

	(1)	(2)	(3)
Variables		**Science**	
Neo_Confucianism	5.905***	2.789***	2.685***
	(1.232)	(0.909)	(0.916)
Writing_intensity		0.379***	0.362***
		(0.065)	(0.065)
In (Dist_tradeport)			−0.130**
			(0.062)
Ricesuit			0.004
			(0.003)
Wheatsuit			−0.001
			(0.002)
Ruggedness			−0.000
			(0.000)
Latitude			0.027***
			(0.010)
Constant	0.169***	0.090***	0.070
	(0.019)	(0.017)	(0.160)
Observations	1303	1297	1296
R-squared	0.154	0.385	0.393

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

of morality-backed social order that could withstand semi-anarchism.[88] Post-war land acquisitions likely played a more fundamental role in the growth of Song Neo-Confucianism, as they widened land disparity. The series of deadly wars demolished the feudal landlords as a ruling class and gave rise to the commoner landlords, who amassed immense fortune through wartime land grabs. This provided the potential for a peasant uprising, which became a reality during the reign of the Song. Faced with this internal political challenge, the Neo-Confucians enthusiastically committed themselves to the reassertion of Confucian canon as the foundation of state legitimacy in response to the egalitarian claims of the grassroots population. In addition to the postbellum societal and political demand for a reinvention of Confucianism, the growing popularity of Buddhism and Daoism (also in response to the war's devastation) presented Confucianism with distinct obstacles. To secure its uncontested status as the state ideology, the Neo-Confucians diligently and creatively reinterpreted the classical Confucian canon through 'mind' and 'morality', in sharp contrast to the philology tradition developed in the late Tang. Given that the war was the primary impetus for the postbellum heterization of ideology, a greater intensity of Neo-Confucian activities in war-torn regions was observed, as Neo-Confucians were subject to heightened anxiety in war-torn regions where moral corruption and social disorder were more prevalent.

Although war directly led to local population reduction and migration, this impact was only seen in the short term. In the long term, the local population loss would be gradually compensated in the post-war period. For instance, the Taiping Rebellion in the mid-nineteenth century caused

[88] Ibid., p. 2.

TABLE 6 Robustness check: exclude the frontier areas.

	(1)	(2)	(3)	(4)	(5)
Variables	**Science**				
Neo_Confucianism	2.941***	2.600***	2.852***	2.952***	2.410**
	(0.911)	(0.926)	(0.913)	(0.916)	(0.964)
Jinshi_density		3.461*			3.385*
		(1.910)			(2.036)
Writing_intensity			13.124		5.185
			(9.367)		(8.641)
Pop_density				0.044*	0.038
				(0.026)	(0.028)
lnctax					0.280**
					(0.140)
In (Dist_trade port)					−0.466
					(0.477)
Ricesuit					0.026
					(0.040)
Wheatsuit					−0.003
					(0.013)
Ruggedness					0.003
					(0.002)
Latitude					0.183
					(0.127)
Province FE	Yes	Yes	Yes	Yes	Yes
Constant	0.045	−0.650	−0.038	−1.086	−7.350**
	(0.532)	(0.595)	(0.527)	(0.927)	(3.614)
Observations	260	260	260	260	260
R-squared	0.480	0.511	0.483	0.486	0.553

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

serious population losses in regions south of the Yangtze River, but a large number of people moved back to that area after the war.[89] Our empirical results show that the wars from the late Tang dynasty to the end of the Five Dynasties and Ten States did not affect the Song Dynasty's scientific and technological output through other channels, such as the density of population, the density of *jinshi*, and the intensity of writing, as presented in table 7, suggesting that the exclusive hypothesis of instrumental variables is satisfied.

To sum up, we employ the war frequency from the late Tang Dynasty to the end of the Five Dynasties and Ten States as instrumental variables of Neo-Confucian spirit. War as an instrumental variable to conduct causal inference has been used in many studies.[90] The 2SLS model is

[89] Li and Lin, 'Taiping tianguo zhanzheng'.

[90] For example, Bao et al., 'The effects of bilateral attitudes'.

TABLE 7 Exclusivity testing of instrumental variables.

Variables	(1) Jinshi_density	(2) Writing_intensity	(3) Pop_density
War	0.003	0.001	1.889
	(0.018)	(0.001)	(1.153)
Jinshi_density		0.018***	1.432
		(0.006)	(2.084)
Writing_intensity	1.799		−29.299
	(1.126)		(20.084)
Pop_density	0.001	−0.000	
	(0.002)	(0.000)	
lnctax	−0.002	0.001	1.002***
	(0.008)	(0.001)	(0.312)
In (Dist_trade port)	−0.013	0.001	0.108
	(0.016)	(0.001)	(0.333)
Ricesuit	−0.001	0.000	0.091
	(0.004)	(0.000)	(0.110)
Wheatsuit	−0.000	−0.000	0.040
	(0.002)	(0.000)	(0.045)
Ruggedness	−0.000	−0.000	−0.017***
	(0.000)	(0.000)	(0.004)
Latitude	−0.007	0.000	0.243
	(0.007)	(0.001)	(0.234)
Province FE	Yes	Yes	Yes
Constant	0.526*	−0.017	4.727
	(0.308)	(0.036)	(8.698)
Observations	287	287	287
R-squared	0.572	0.180	0.597

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

shown in the following specifications [(3) and (4)]:

$$\text{Second stage}: Science_i = \alpha_2 + \beta_2 Neo\_\hat{Confucianism}_i + \theta_2 X_i^c + \delta_p + \varepsilon_{2i} \quad (3)$$

$$\text{First stage}: \hat{Neo\_Confucianism}_i = \alpha_3 + \lambda_1 war_i + \theta_3 X_i^c + \delta_p + \varepsilon_{3i} \quad (4)$$

We report the above 2SLS estimations in table 8. The results of the first stage show that the war frequency from the late Tang Dynasty to the end of the Five Dynasties and Ten States is significantly positively correlated with the Neo-Confucian spirit. The Wald *F* statistics are above the standard threshold of 10 suggested by Staiger and Stock,[91] implying that our instruments are not weak. The results of the second stage then show that after controlling for potential endogeneity

[91] Staiger and Stock, 'Instrumental variables'.

TABLE 8 Effect of Neo-Confucianism on science: 2SLS estimations.

	(1)	(2)	(3)	(4)	(5)
Second stage	**Science**				
Neo_Confucianism	6.372***	6.193***	6.356***	5.852***	5.267***
	(1.820)	(1.825)	(1.815)	(1.719)	(1.883)
Jinshi_density		2.704			2.843
		(1.861)			(1.901)
Writing_intensity			4.702		1.916
			(4.657)		(5.279)
Pop_density				0.029	0.030
				(0.020)	(0.024)
lnctax					0.145
					(0.125)
In (Dist_trade port)					−0.498
					(0.433)
Ricesuit					0.043
					(0.036)
Wheatsuit					−0.007
					(0.012)
Ruggedness					0.003*
					(0.001)
Latitude					0.216*
					(0.114)
Province FE	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
First stage	**Neo_Confucianism**				
War	0.138***	0.137***	0.138***	0.143***	0.136***
	(0.029)	(0.030)	(0.291)	(0.028)	(0.027)
Baseline controls	Yes	Yes	Yes	Yes	Yes
F statistics	22.797	21.515	22.412	25.856	25.740
Observations	287	287	287	287	287
R-squared	−0.023	0.023	−0.021	0.010	0.134

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

with instrumental variables, the effect of Neo-Confucian spirit on scientific and technological works is significantly positive. Taken together, these results confirm the hypothesized importance of war (859–959) in determining the availability of Neo-Confucian spirit, and consequently, a prefecture's success in scientific and technological output.

V | THE ROLE OF CONFUCIAN ACADEMIES

Qian said, 'The spirit of Song Learning is manifested in two aspects: one is the reform of government decrees, the other is the formation of the doctrine of Confucian Classics, and the

spirit resides in the Confucian academy'.[92] The academy arose during the Tang Dynasty, subsequently institutionalized as an educational organization for discourse on learning in the Song Dynasty. During the Southern Song Dynasty, more than 500 academies existed and 299 more were erected, surpassing the amount and distribution of previous dynasties by a significant margin.[93]

There are two main reasons to explain the prosperity of Confucian academies in the Song Dynasty. On the one hand, with the gradual decline of the Southern Song dynasty regime, the decadence of official education and the corruption of the imperial civil examination spurred the growth of academies. Zhu Xi even condemned the '*Taixue*', the foremost institution of imperial learning at the time, for its utter decadence.[94] On the other hand, as the development of Neo-Confucianism entered its mature phase, Neo-Confucians found that academies could be utilized to promote their own doctrines, and that the curriculum and teaching methods could be tailored to fit their pedagogical aims.[95] Neo-Confucians became a dominant force in the establishment of academies. For instance, Lü Zuqian (1137–81) discoursed on learning in Wuzhou and built the *Lize Academy*, and Zhang Shi (1133–80) discoursed on learning in Tanzhou and built the *South of the prefecture Academy*. Among them, the Neo-Confucian who contributed the most to the establishment of the academy is Zhu Xi. He founded more than 10 academies, the most notable of which were the restoration of the *White Deer Grotto Academy* in Jiangzhou and the discourse on education at the *Yuelu Academy*.

It is worth mentioning that the teaching function of the academy was enhanced in the Song Dynasty, and the scope of research was more extensive. Not only was the traditional Confucian ethics discipline involved, but a lot of applied knowledge of science and technology was also imparted to their disciples. For instance, Hu Yuan (993–1059) was not only proficient in the study of rhythm, leaving an indelible mark in the history of Chinese metrology, but was also renowned for initiating a teaching method known as '*fenzhai jiaoxue*' in the *Anding Academy* of Huzhou, which teaches practical courses on scientific and technical knowledge such as military, hydraulic engineering, arithmetic, etc., in addition to the traditional Confucian classics. Liu Yi (1029–91), one of Hu Yuan's disciples, was proficient in water conservation and later served as an official of the water ministry. In addition, he wrote *The Prescriptions for Correcting Custom* (*Zhengsu Fang*), which altered the local custom of advocating witches and ghosts, and ordered many wizards to change their professions to medicine.[96] In addition, influenced by Zhu Xi's extensive study of the natural sciences, many of his disciples were interested in technology and science, among whom Cai Shen (1135–98) and Cai Yuanding (1167–230) were the representatives.[97] Neo-Confucian spirit not only stimulated the Neo-Confucians themselves to engage in scientific and technological endeavours, but also propagated the Neo-Confucian spirit through the Confucian academy. In other words, Confucian academies were used as a channel for the dissemination of Neo-Confucian spirit and its influence on scientific and technological output.

[92] Qian, *Zhongguo jin sanbai nian xueshu shi*.

[93] Bai, *Zhongguo gudai shuyuan*, p. 10.

[94] Zhu, *Zhu Wengong wenji*, *juan* 69.

[95] Ibid., pp. 230.

[96] Ibid., *juan* 1.

[97] Cai Yuanding was proficient in astronomy, geography, music, and military affairs (Ibid., *juan* 62, biography of Cai Yuanding).

TABLE 9 Role of Confucian academies: OLS and 2SLS estimations.

	(1)	(2)	(3)	(4)
	Science		Scientist	
Neo_Confucianism*Academy_density	4.868*	7.243**	3.665**	8.374***
	(2.754)	(3.443)	(1.591)	(2.446)
Neo_Confucianism	0.689	0.874	0.399	1.774*
	(0.762)	(1.192)	(0.522)	(1.002)
Academy_density	0.709	−0.142	−0.223	−2.050**
	(0.900)	(1.416)	(0.415)	(0.865)
Writing_intensity	1.049	0.750	3.886	2.744
	(4.913)	(4.732)	(2.592)	(2.237)
Jinshi_density	2.329	2.129	0.000	−0.503
	(1.987)	(1.831)	(0.475)	(0.628)
Pop_density	0.021	0.021	0.023*	0.023*
	(0.022)	(0.020)	(0.012)	(0.013)
lnctax	0.252**	0.235**	0.132**	0.064
	(0.109)	(0.107)	(0.052)	(0.060)
In (Dist_trade port)	−0.401	−0.385	−0.032	−0.011
	(0.415)	(0.396)	(0.077)	(0.113)
Ricesuit	0.010	0.014	−0.012	0.005
	(0.032)	(0.027)	(0.013)	(0.017)
Wheatsuit	0.007	0.008	0.011	0.011
	(0.011)	(0.011)	(0.008)	(0.010)
Ruggedness	0.003*	0.002*	0.001**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Latitude	0.130	0.126	−0.010	−0.002
	(0.103)	(0.105)	(0.042)	(0.053)
Constant	−5.279*		−1.641	
	(3.005)		(1.562)	
Province FE	Yes	Yes	Yes	Yes
First stage		Neo_Confucianism		Neo_Confucianism
War		0.153***		0.153***
		(0.036)		(0.036)
Baseline controls		Yes		Yes
F statistics		10.716		10.716
Observations	287	287	287	287
R-squared	0.601	0.268	0.567	−0.028

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Although there were no stringent restrictions on school age for the enrolment of Song Dynasty academies, it should be mentioned that the majority of students were adults, and the enrolment age was generally over 15 years old. Moreover, some Confucian masters also set entrance examination programmes for the purpose of further education and teaching students according to their

aptitude.[98] In other words, the Confucian academies of the Song Dynasty were not responsible for abecedarian education where such elementary learning was usually provided by old-style official or private schools.[99]

To examine whether Confucian academies can serve as a channel for the effect of Neo-Confucian spirit on scientific and technological output in a prefecture, we add an interaction term, $Neo\_Confucianism_i \times Academy\_density_i$,[100] into the benchmark model as shown in the following specification (5):

$$Science_i = \alpha_4 + \mu_1 Neo\_Confucianism_i \times Academy\_density_i + \beta_4 Neo\_Confucianism_i + \gamma_4 Academy\_density_i + \theta_4 X_i^c + \delta_4 + \varepsilon_{4i} \quad (5)$$

Column 1 of table 9 reports the OLS estimate of the interaction term, which shows that the interacting effect of Neo-Confucian spirit with Confucian academies has a significant and positive impact on scientific and technological production. Moreover, the results of employing the war frequency as an instrumental variable of Neo-Confucian spirit are strikingly similar, as shown in column 2, which indicates that the more Confucian academies in a prefecture, the stronger the positive effect of Neo-Confucian spirit on local scientific and technological output. To check their robustness, we replace scientific and technological works with technologists and scientists, and run the regressions again. As reported in columns (3) and (4), the results reaffirm the earlier findings.

VI | CONCLUSION

Whether Confucian culture fettered or promoted science has been debated since the New Culture Movement. Joseph Needham's work *Science and civilisation in China* set the negative tone that Confucian culture hindered science, and this dominated for a long time. On the contrary, there are not a few scholars who demonstrate that Confucianism contains factors that have positive impacts on the development of science and technology.[101] As elaborated in the introduction, the research question is vital, yet the connotative intricacy of Confucianism prevents us from conducting a straightforward analysis.

To reconcile these conflicts, we focused on dismantling the notion of Neo-Confucianism in the Song Dynasty context. By constructing the indices of the Neo-Confucian Spirit characterized by the pursuit of principle (*li*), broad learning, and scepticism on the basis of Confucian works in the Song Dynasty, and measuring the development of science and technology through scientific and technological works, we examined the effect of the rise of Neo-Confucianism on science and technology in the Song time. Our empirical investigations show that Neo-Confucian spirit had a considerable favourable effect on the production of Chinese medieval science and technology in cross-sectional regressions, and Confucian academies served as a channel for the effect of Neo-Confucian spirit on scientific and technological output. Our robustness was checked

[98] Liu, *Songdai shuyuan*, p. 150.

[99] Feng, *Liangsong ruxue*, p. 9.

[100] *Academy _density* is measured by the number of academies per square kilometre, and the data are obtained from Bai, *Zhongguo gudai shuyuan*, pp. 4–26.

[101] Ibid.

and 2SLS using generic instrumental variables dealing with potential endogeneity confirmed the benchmark results.

Needless to say, although China was not as successful as the Europeans of their time in developing modern science and industrialization, this did not indicate a lack of interest in technology and natural sciences among Song Neo-Confucians. Instead, Neo-Confucian spirit cultivated a learned group that contributed to scientific and technological progress in Medieval China, or at least in the Song Dynasty. It should be noted that although this paper establishes that Song Neo-Confucianism was conducive to the development of science in medieval China, it does not purport the claim that Song Neo-Confucianism served as an impetus or catalyst for the development of modern science in China, or that it could have contributed to the emergence of Newtonian science in China in the absence of Western influence.

Indeed, in a recent study, Dong and Zhang show that the development of Neo-Confucianism during the Ming and Qing periods did not contribute to the rise of modern science in China.[102] Note that at least two factors had contributed to the alteration in the connection between Neo-Confucianism and science. First, Neo-Confucianism integrated the elements of Buddhism during the Ming Dynasty, especially under the influence of the Zen sect, which gradually replaced the Song Neo-Confucianism (*Li xue*) tradition with the learning of the mind (*Xin xue*), to the extent that the Song Neo-Confucian spirit was completely abandoned. Second, there are essential distinctions between modern and medieval science. The rise of modern science in Europe during the seventeenth century was based on the Baconian method, which replaced and rejected the Aristotelian philosophy adopted by medieval science. In contrast, the absence of a natural philosophy akin to Aristotelianism during the Axial Age, coupled with the lack of a dominant transcendental religion later, ultimately gave rise to an empirical developmental model within Chinese science from antiquity until the pre-modern era. It is precisely this linear growth paradigm of Chinese science that hindered the emergence of modern science in China. Nonetheless, it is worth noting that the prevalence of geography, medicine, and agronomy in medieval Chinese science, characterized by empiricism, was similar to that of medieval European science, making the development of science in the Middle Ages comparable across the Orient and Occident.

Since both Neo-Confucianism and science had undergone substantial changes from the Middle Ages to modern times, it would be misleading to carry the narratives of the current paper over to modern times. The question of whether Neo-Confucianism was to blame for the stagnation of Chinese science during the Ming and Qing periods is an important scholarly topic worth pondering but beyond the scope of the current paper.

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[102] Dong and Zhang, 'Confucianism and science'.

DATA AVAILABILITY STATEMENT

The data and replication files for this paper are available on the Economic History Review's website as well as on OpenICPSR at: https://doi.org/10.3886/E196941V2

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