# The Jesuits and Chinese Science

Chicheng Ma*

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**Abstract**: Based on the historical context of the Jesuit mission to China between 1560 and 1820, this paper examines the role of knowledge diffusion in scientific production. To facilitate their China mission, the Jesuits introduced European sciences to Chinese cultural elites—the Confucian literati. This stimulated the literati toward scientific research. In places where the Jesuits diffused European sciences, the number of Chinese scientific works increased significantly. The finding questions the conventional wisdom that the Confucian literati of imperial China disparaged science, and demonstrates the importance of access to new knowledge in scientific progress.

**Keywords**: Jesuits; Science; Knowledge Diffusion; Elites; Human Capital; China
**JEL Codes**: N35; N75; O15; O33; Z12

* Faculty of Business and Economics, The University of Hong Kong, Pokfulam Road, Hong Kong. Email: macc@hku.hk. I thank Ying Bai, Zhiwu Chen, Jeremiah Dittmar, Ruixue Jia, James Kung, Jin Li, Kaixiang Peng, Lingwei Wu and the seminar participants at the National University of Singapore, Lingnan University, Hong Kong Baptist University, Economic History Workshop (HKU), and The Sixth Asian Historical Economics Conference for helpful comments. Xinhao Li, Xinran Liu, Xinning Ren and Xiaofan Zhu provided excellent research assistance.

## 1. Introduction

Thanks to the missionary expansion of the Jesuits from the 1560s, European sciences were introduced to Confucian China. It brought about the first wave of intellectual contact between the two civilizations. This article examines how the Jesuits interacted with the Confucian literati to affect Chinese scientific progress, and through this interaction we demonstrate the importance of access to new knowledge in scientific production.

To facilitate their missionary work, the Jesuits sought the support of the literati—the cultural and political elites of the imperial China. To do this, the Jesuits used European sciences to pursue the literati since the European sciences could attract the interest of these learned elites and help establish the prestige of the Jesuits (Brockey 2007). Between 1580 and 1800, the Jesuits translated about 130 titles of European scientific works into Chinese. The majority pertained to astronomical and mathematical knowledge achieved since the Renaissance. They also introduced to China many scientific inventions; these included the telescope, proportional compass, barometer, mechanical clock, and cannon, among others (Tsien 1954). The knowledge diffusion did not end until the late 18$^{th}$ century when the Pope dismissed the Jesuit order.

Despite its early success, Chinese science had gradually fallen into stagnation after the 14$^{th}$ century. Instead, the Confucian moral philosophy became predominant in Chinese intellectual circles (Needham 1969; Huff 1993; Bol 2008). European sciences introduced by the Jesuits were novel to Chinese intelligentsia, and were somewhat superior to Chinese classical sciences in many aspects. The effect of this great wave of intellectual contact on Chinese science, however, remains a paradox.

A conventional view is that the Chinese literati had no interest in learning from the West. This is best summarized by David Landes (2006, pp. 11, 12, and 15): "such [Confucian] cultural triumphalism combined with petty down-ward tyranny made China a singularly bad learner... The response, then, had to be a repudiation or depreciation of Western science and technology... One consequence was a prudent, almost instinctive, resistance to change." The lack of interest in science might be reinforced by the overwhelming imperial civil examinations or *keju*. As the only way of upward social mobility, *keju* exams occupied Chinese scholars in their study of Confucian classics—the exam curriculum—rather than science (Baumol 1990; Huff 1993; Lin 1995). As a result, Ming-Qing China lost the opportunity and momentum to keep up with Europe in the pursuit of modern science.

An opposite view, however, is that the Jesuits revived Chinese science. After having recognized the superiority of the European sciences, many literati took the initiative to learn

European sciences from the Jesuits, then attempted to re-construct Chinese classical sciences, especially astronomy and mathematics, based on the European methods. This fostered an intellectual movement of "concrete studies" or *shixue.* The Chinese literati began to criticize the metaphysical nature of Confucian classics, but emphasized the studies of natural phenomena (Yu 1975; Gernet 1982; Henderson 1984; Elman 1984). Between 1580 and 1840, the Chinese literati produced a total of 440 book titles on sciences, more than triple that which was produced in the two centuries before the Jesuits came to China.

To quantitatively assess the merit of these different views, we constructed a panel data of 252 Chinese prefectures between the years 1500 and 1840. We manually checked the biographies of all 433 Jesuits who came to Ming-Qing China; these were collected by the Jesuit Joseph Dehergne (1973). Based on the records of the location and time of each Jesuit's activities, we enumerated the number of Jesuits by prefecture and decade. To measure Chinese scientific production, we used the number of scientific works (book titles) written by the Chinese. The recorded scientific works in history were compiled by the Chinese Academy of Sciences as the *Collections of Chinese Classics on Science and Technology.* According to the authors' biographies, we identified the location and period of the publication of each book.

The distribution of the Jesuits was arguably exogenous to the local conditions within China. Given China's autarkic regime and predominantly Confucian culture at the time, imperial authority was hostile to the unacquainted Europeans. According to the records in the Jesuits' diaries, whether and when the Jesuits could reside in a place largely depended on 'coincidence', especially whether they could meet an official friend who was willing to provide help and protection (Ricci and Nicolas 1615; Brockey 2007). To further rule out the possibly confounding factors that affected both the distribution of the Jesuits and Chinese scientific production, we controlled for local population size, economic prosperity (agricultural productivity and urbanization rate), number of literati, and the geographic factors of distance to coast, distance to navigable river, terrain ruggedness, and land area.

To identify that the effect of the Jesuits on Chinese scientific production came from their introduction of European sciences, we distinguished the Jesuit scientists from Jesuit priests. Jesuit scientists refer to the Jesuits who were involved in scientific activities while they were preaching in China. Their scientific activities mainly included translating European scientific works, introducing European inventions, conducting scientific surveys and tutoring, among others. Jesuit priests refer to the Jesuits who did only missionary work. The Jesuit scientists and priests were similar in almost everything except for this difference in the spreading of science. We used the number of Jesuit scientists to measure knowledge diffusion, while the number of Jesuit priests was used as a placebo. Only Jesuits scientists had a positive effect on Chinese scientific production, but not the Jesuit priests. On average, an additional Jesuit scientist would increase Chinese scientific works by 0.245 or 420% when evaluated by the sample mean (0.056) of Chinese scientific works. This large marginal effect is consistent with historical facts that a single Jesuit scientist could translate a series of European scientific books and enlighten a large number of literati in China.

Certainly, Chinese scientific production could have been shaped by some unobserved correlates of the Jesuits. To further address this concern, we restricted the analysis to only the prefectures where there were Jesuits but that varied by the number of Jesuit scientists. Doing so largely reduced the heterogeneities behind the geographic distribution of the Jesuits in China. The effect of Jesuit scientists on Chinese scientific production remained robust. Moreover, we used the number of Chinese novels as a falsification test. If the effect of Jesuit scientists on Chinese scientific production came from the unobserved correlates of the distribution of the Jesuits, we should also observe these effects in other Chinese writings. But the results show that Jesuit scientists had no effect on the number of Chinese novels. In the same vein, we found that the Jesuit scientists had a greater impact on Chinese astronomy and mathematics relative to the impact on other scientific fields. This is consistent with the fact that astronomy and mathematics were the mainstream of the Jesuits' knowledge diffusion in China.

The question that follows is whether the effect of the Jesuits' knowledge diffusion on Chinese scientific production was through the interaction between the Jesuit scientists and the Chinese literati, or it was just the number of Jesuit scientists that mattered. In China's Ming-Qing period (1368-1911), the literati were mostly degree holders conferred by the competitive *keju* exams. We used the number of *jinshi* holders as a proxy for the number of literati. As the highest academic qualification in *keju* exams, *jinshi* were held in the highest regard. They were also the primary intellectual group that the Jesuits tried to pursue and influence. By regressing Chinese scientific works on the interaction term between the number of Jesuit scientists and the number of *jinshi* holders, we found that the effect of the Jesuit scientists on Chinese scientific production was greater where there were more *jinshi*. In prefectures where there was no *jinshi* (meaning a very weak presence of educated elites), the effect of the Jesuit scientists on Chinese scientific production was close to zero.

The empirical results coincide with historical anecdotes that many Chinese scholars turned to scientific research after they accessed European sciences though the Jesuits. This stands opposed to the conventional wisdom that the Chinese intelligentsia in the 16$^{th}$-18$^{th}$

centuries disparaged science and resisted to learn from the West (Cipolla 1967; Baumol 1990; Lin 1995; Landes 2006). In fact, given the demand for the knowledge of statecraft, the *keju* exams never excluded scientific knowledge, but also tested astronomy, mathematics, military sciences, and agriculture, among others, in the policy questions (Elman 2000). Moreover, given the slim chance of receiving a government appointment, *keju,* in fact, created a large literate group outside the bureaucracy. These educated elites turned to other professions as teachers, merchants, doctors, and consultants, among others (Schafer 2011; Elman 2005). Thanks to the Jesuits, the new and valuable European knowledge met the literati's demand for fortune and fame.

The findings of this paper indicate the importance of access to Western knowledge flow in China's historical scientific progress, despite the Jesuits' scientific influence being confined to only a small circle of knowledge elites, rather than an industrial enlightenment. Moreover, China's 'European window' of knowledge flow was closed again after the Jesuits ended their China mission in the late 18$^{th}$ century, and was not reopened until the mid-19$^{th}$ century. From thereon, China began its modern transition under a new and more substantial wave of Western influence and the Chinese elites' 'self-strengthening' efforts (Spence 1990; Jia 2014; Bai and Kung 2015; Yuchtman 2017).

Beyond the implication for Chinese economic history, this study provides new historical evidence to the literature that stresses the importance of knowledge diffusion in knowledge production (Romer 1986; Mokyr 1990, 2005; Borjas and Doran 2012; Waldinger 2010, 2016; Moser, Voena and Waldinger 2014; Chaney 2016; Iaria, Schwarz and Waldinger 2018), and more broadly in human capital formation and development (Becker and Woessmann 2009; Dittmar 2011; Cantoni and Yuchtman 2014; Hornung 2014; Squicciarini and Voigtländer 2015; Dittmar and Seabold 2017; Becker, Grosfeld, Grosjean, Voigtlaender, and Zhuravskaya 2018).

In particular, this paper is related to the studies on the positive role of Catholic missions in human capital formation and development in South America in the 17$^{th}$ and 18$^{th}$ centuries (Waldinger 2017; Valencia Caicedo 2018). The difference is this: when the Catholic missions arrived in China, China was already a highly civilized empire, having a predominant Confucian intelligentsia. This unique historical setting enabled us to gauge the interaction between the two groups of learned elites in the process of knowledge transfer. Our finding suggests that the effective knowledge transfer depended not merely on the effort of the knowledge suppliers (the Jesuits), but also the positive response of the knowledge receivers (the literati).

## 2. Historical Background

As a European Catholic order, the Society of Jesus began the global mission in the mid-16$^{th}$ century. That Macau was occupied by Portugal in 1557 facilitated the Jesuits' expansion to East Asia. The Jesuits first arrived at Macau in 1562. Later, thanks to the diplomatic efforts and relationship of Jesuit Michele Ruggieri (1543-1607) with the local officials of Guangzhou, the Jesuits were allowed to enter mainland China in 1582. The Jesuit mission in China stabilized and flourished after the Jesuit leader Matteo Ricci was allowed by the Ming emperor to reside at the imperial capital Beijing in 1601 (Brockey 2007). By the 1700s, the Jesuits had missionized 90 out of the 252 prefectures (35%) of China Proper (Dehergne 1973).

After 1710, however, the Jesuits began to decline in China. The main reason was the Chinese Rites controversy between the Roman Catholic Church and the Qing emperors circa 1704-1775. The Popes Clement PP. XI and Clement PP. XIV successively decreed that Chinese Catholics had to abandon the Confucian rites of ancestor worship since it was a religious rite that contradicted the Catholic faith. The Qing emperor could not tolerate this decree and after this diplomatic failure, the Qing authority began to expel the Jesuits. Meanwhile, the Jesuits had also gradually lost their position in Europe. Portugal and France, for example, banned Jesuit activities in 1759 and 1764, respectively. The Jesuits finally ended their China missions after the dissolution of the order by the Pope in 1773 (Brockey 2007). The last Jesuit in China, L. de Poirot, died in Beijing in 1813 (Standaert 1991).[1]

### 2.1. The Jesuits' Knowledge Diffusion in China

To facilitate the missions in China, the Jesuits sought the support of the literati. In communicating with the literati, Matteo Ricci found that he was welcomed not because of his Catholicism, but his scientific knowledge and instruments. Ricci began to use the European sciences to cultivate the literati. From thereon, science became the principal instrument of the Jesuits' missionary expansion in China (Gernet 1982). Not only were the Jesuits qualified to use science to missionize China, a unique feature of the Jesuits is their distinct academic qualification. Most Jesuits were well-educated in science and philosophy. Prior to being sent to China, the Jesuits learnt the Chinese language and culture in academies either in Rome or Portugal (Xiong 1994).

[1] Following the Jesuits, the Franciscans, Dominicans, Congregation of Priests of the Mission, and Paris Foreign Missions Society also entered China in the mid-17$^{th}$ century, but their activities were of a much smaller scale compared to that of the Jesuits before 1800 (Cui 2006). There were no systematic records on the number of priests of these Catholic missions in China.

Between 1580 and 1800, the Jesuits translated over 130 European scientific titles into Chinese. The majority pertained to astronomy (67%), followed by mathematics (15%). The others were in physics, chemistry, biology, geography, medicine, and engineering, among others. Most translations introduced the scientific achievements since the Renaissance. The new knowledge substantially broadened the intellectual horizon of the Chinese literati (Tsien 1954). In astronomy, for instance, after Chinese astronomer Guo Shoujing (1231-1316) published *Shoushi Li (Granting the Seasons)* in 1281, no new astronomical work was produced in China until the coming of the Jesuits three centuries later. By compiling the *Summary of Astronomy* (*Tian Wen Lue*) in 1615, Manuel Dias introduced Galileo's astronomy and telescope. Chinese scholars also found the European celestial system to be more accurate than that used in China.

Similarly, in mathematics, Matteo Ricci translated Christopher Clavius' *The Commentary on Euclid's Elements* (*Jihe Yuanben*) to Chinese in 1607 (Appendix Figure A1). *The Elements* was regarded by Chinese scholars as 'the crown of Western studies'. As for geographical studies, by translating Abraham Ortelius' *Theatre of the World* (*Huanyu Gaiguan*) in 1584, Ricci introduced China to the first modern world map and cartography. Ricci even presented Western psychology in this same manner: by translating *Treatise on Memory (Xiguo Jifa)* in 1595, Ricci pointed out that the brain is the seat of memory, which challenged the traditional Chinese view that the seat of memory lies in the heart (Tsien 1954).[2]

The Jesuits also introduced many European inventions and scientific instruments to China. For example, Ferdinand Verbiest (1623-1688) re-equipped the Beijing Ancient Observatory with new celestial instruments from Europe (Appendix Figure A2). Another well-known example is the mechanical clock. Matteo Ricci was credited with being the first person to introduce the Chinese to mechanical clocks. The workings and mechanism of these clocks were not only well-received, but impressed the Chinese so much so that many literati wrote poems to express their love and admiration for its creation. The Jesuits also introduced many other novel things; these included triple prism, microscope, thermometer, cannon, music box, globe, glasses, and other manufactured goods (Tan 2011).

From the 1680s, the diffusion of European sciences to China reached new heights. This was largely due to the arrival of French Jesuit scientists from the Royal Academy of Sciences in Paris. Upon the request of the Society of Jesus, King Louis XIV sent a total of 15 scien-

[2] Likewise, another Italian Jesuit, Sabbathin de Ursis (1575–1620), introduced Western hydraulic techniques to China in his book *Western Methods on Water Conservancy* (*Taixi Shufa*) in 1612. His *Notes of Medicine* (*Yao Lu Ji*) in 1617 was probably the first to systematically introduce Western pharmacology to China (Tsien, 1954).

tists, in the name of the King's Mathematicians, to aid the Jesuits' scientific activities in China (Jami 2012).[3] These academicians were much more accomplished in mathematics and astronomy than their Jesuit predecessors. Moreover, during their period of work in China, they kept in close contact through continual correspondences with the scientific communities in Europe. For instance, the Royal Society of London regularly delivered the periodical of *Philosophical Transactions* to the French mathematicians in China. Joachim Bouvet (1656-1730), an eminent scientist who worked in China between 1687 and 1730, had 14 recorded correspondences with Gottfried Leibniz (1646-1716) throughout their mathematical research exchange (Landry-Deron 2001).

The King's Mathematicians conducted many scientific surveys, both in the imperial palace and outside of its premises. They carried more than 30 new scientific instruments to China; these included the quadrants, micrometers, telescopes, equatorial scale plates, and barometers, among others. Using these instruments, they conducted large-scale celestial observations and ground mapping across China (Landry-Deron 2001). They also taught Chinese scholars mathematics and astronomy at the imperial palace, and assisted with the compilation of encyclopedic books on these two subject matters. A good example of their influence is with the compilation of *Yuzhi Shuli Jingyun* (Essence of Numbers and Their Principles) in 1722, which introduced the logarithmic table, iterative method of high order equation, and the calculation of infinite series. This book influenced a number of Chinese mathematicians in the late 18$^{th}$ century (Du and Han 1992; Elman 2005).

Relative to their knowledge diffusion, the Jesuits' missionary achievement was considered trivial. In the heyday of the Jesuit's China mission (around 1700), the total number of Chinese Catholic converts was approximately 200,000 (Standaert 1991), which accounted for merely 0.1% of the Chinese population.

### 2.2. Chinese Response to European Sciences

Despite its early success, Chinese science gradually fell behind that of Europe after the 14$^{th}$ century (Needham 1969). Instead, the Confucian moral philosophy dominated the Chinese intellectual realm (Bol 2008). Meanwhile, China went autarkic upon the establishment of the Ming dynasty in 1368. The Ming authority imposed a strict 'sea ban' policy to crack down

[3] The representatives were Jean de Fontaney (1643-1710), Joachim Bouvet (1656-1730), Jean-François Gerbillon (1654-1707), Dominique Parrenin (1665-1759), and Pierre Jartoux (1668-1720), among others. Most of them had already been prestigious mathematicians and astronomers in Europe before they left for China. For example, as a teacher of mathematics and astronomy at the College Louis le Grand, Jean de Fontaney had published many scientific books (Landry-Deron 2001).

on foreign trade and communications, and hence China maintained little intellectual contact with the West before the arrival of the Jesuits. The Jesuits' introduction of European sciences gave the Chinese Confucian scholars new impetus to learning and knowledge acquisition (Gernet 1982).

Given that they were in an environment entrenched in conservative, Confucian traditions, Chinese scholars were often perceived to have had no interest in scientific research. The lack of interest may have been compounded by the incentive scheme under the *keju* exam. As a meritocratic institution, *keju* was designed to recruit qualified officials by examinations. The *keju* exam offered commoners a 'ladder of success' through entering the gentry class and officialdom. The scholar-officials received the highest regard in imperial China. They enjoyed a high income, and a set of political, social and cultural privileges ranging from the exemption from corporal punishment to ritualistic recognitions (Chang 1955).[4] As a result, the *keju* absorbed talent into the study of Confucian philosophy for exam success rather than scientific research. Such "misallocation of talents" is deemed as one of the reasons behind the Needham Puzzle, the enigma as to why China failed to develop modern science after the $14^{th}$ century (Huff 1993; Lin 1995).

But many historical stylized facts suggest an opposite possibility. The introduction of the novel European sciences shocked China's Confucian intelligentsia. As recorded in Ricci's diary, when he introduced the principle of European geography and astronomy to China, Chinese scholars found this knowledge astounding and totally beyond their imagination (Ricci and Trigault 1615). This stimulated the literati's curiosity for the new knowledge. After having recognized the backwardness of Chinese science, the literati learnt European science from the Jesuits, and attempted to revisit Chinese classical sciences using the European methods. A good example is the monumental work on Chinese astronomy, *Lixiang Kaocheng Houbian (Sequel of Investigation on Calendar and Astronomy)*, where Giovanni Cassini's calendar calculation methods were emphasized (Gernet 1982). Likewise, the Qing scholars Huang Zongxi (1610-1695), Wang Fuzhi (1619-1692) and Ruan Yuan (1764–1849) attempted to absorb European mathematical method in re-constructing Chinese classical mathematics (Hsiao 2014).[5]

[4] While comprising only 2% of the population, the *keju* scholars accounted for almost a quarter (24%) of the nation's income (Chang, 1955).

[5] Some scholars' scientific pursuit even went beyond the textual reconstruction of the classics; they also gave rise to applied scientific methods to study natural phenomena, and even reiterated the importance of physical experiment as a way of obtaining knowledge (Black 1989; Schafer 2011). A case in point is Song Yingxing (1587-1666), who compiled the encyclopedia of Chinese technologies, *Tian Gong Kai Wu (Natural Works and Crafting)*. In the book, Song systematically recorded various technologies with detailed classifi-

Overall, the Jesuits stimulated a wave of intellectual movement that emphasized science and 'concrete learning' (*shixue*) in China from the late 16$^{th}$ century, though the movement was less revolutionary than that of contemporaneous Europe (Gernet 1982; Rowe 2001; Elman 1984, 2005).[6] Henderson (1984) vividly describes this movement as that of the cosmology being replaced by the astronomy. Or, stated differently, the moral philosophy of Confucianism was replaced by the erudite and critical academic discourse (Yu 1975).

Throughout this process, personal communication with the Jesuits was crucial for the Chinese scholars' scientific achievements. Chinese scholars received systematic, nuanced instruction from their Jesuit friends in regard to novel European science. This was especially true in the collaboration between Chinese scholars and the Jesuits in translation works. To ensure their Chinese writings were acceptable, the Jesuits needed the Chinese scholars' aid. "It was the usual practice for the text to be orally translated by the foreigners, and for a Chinese then to dictate a correct version" (Tsien 1954, p. 307). This provided the Chinese literati with a good opportunity to systematically study the European sciences. For example, the Ming literati Wang Zheng (1571-1644) became a renowned physicist because he could "learn from the three Jesuit teachers [Nicholas Longobardi, Johann Schreck, and Johann von Bell] day and night". He even painstakingly learnt Latin from Nicolas Trigault in his fifties, when he was already a *jinshi* holder (Terentius and Wang 1627, in Zou 2011). Moreover, Chinese scholars learnt from the Jesuits' academic lectures and demonstration of European inventions. As recorded in Matteo Ricci's diary, Ricci often attended the Chinese literati's gatherings. The local literati humbly listened to Ricci's talks on Chinese classics and Western sciences (Ricci and Trigault 1615).

**Matteo Ricci and Xu Guangqi.** A representative case of the Jesuits' impact on the Chinese literati's scientific pursuit is the relationship between Matteo Ricci and Xu Guangqi (1562–1633) (Appendix Figure A3). The chronical records of Xu Guangqi clearly demonstrate the change in his academic pursuit after coming into contact with the renowned Jesuit scientist Matteo Ricci (Appendix Table 1).

Born in the Songjiang Prefecture of Jiangsu Province, Xu Guangqi was a typical Confucian scholar of the Ming dynasty. Before 1604, Xu mainly studied and taught Confucian classics in local schools, and obtained his *shengyuan* and *juren* degrees in 1581 and 1597, re-

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cation and graphic notes. These technologies included European metallurgy, welding, and medicines, among others (Schafer 2011).

[6] Henderson (1984) vividly describes this movement as that of the cosmology being replaced by the astronomy. Or, stated differently, the moral philosophy of neo-Confucianism was replaced by the erudite and critical academic discourse (Yu 1975).

spectively.[7] In 1599, Xu saw a copy of Matteo Ricci's world map. As Xu said, the map shocked his spiritual world, and inspired his interest in European sciences (Zhang and Tang 2011).

Xu's academic research turned to science after he established a close relationship with Ricci in 1604. After obtaining the highest *jinshi* qualification in 1604, Xu entered the Imperial Academy at Beijing as a *Hanlin* Scholar. From then, Xu maintained close contact with Ricci who had settled in Beijing from 1601. Xu began to systematically learn European sciences from Ricci and assisted him in the translation of European scientific works. Through Ricci, Xu was able to appreciate the rationale and methodology behind European science. In the preface he wrote for the *Tongwen Suanzhi*, a mathematical treatise by Ricci based on Christopher Clavius' (1585) *Epitome Arithmeticae Practicae* in 1614, Xu said:

> *"In addition to the discourse on Catholicism, Father Ricci often taught me the principle of mathematics. His religiosity and reasoning are truthful and stripped of rhetoric. Just as leaves adhered to the branches, his scholarship in astronomy and mathematics are solidly rooted in sound theoretical foundations. The real renaissance scholars like them are those who have been studying Western subjects for many years. Father Ricci and his colleagues' mathematical talents is many times those of their peers in the Han and Tang dynasties. We should all learn and benefit from their teaching.*"

Having recognized the lack of logical reasoning and mathematical backwardness in Chinese science, Xu applied European sciences in the study of Chinese mathematics, astronomy, agriculture, and military sciences. Between 1605 and 1633, he finished about 27 works on sciences (Appendix Table A1). Based on Tycho Brahe's (1546-1601) astronomical system, for instance, Xu compiled the encyclopedic *Chongzhen Almanac* during 1629-1634, developing a new and more accurate calendar that is used to this present day. Another of Xu's important work is *Nongzheng Quanshu (Complete Treatise on Agricultural Administration)* published in 1627. It systematically introduced the impacts of climate, geography, irrigation, and superior species on agricultural productivity. The planting of the New World staple crops (potatoes) was also first introduced in the book. Xu even conducted agricultural experiments of transplanting potatoes and cotton from north to south China in Shanghai between 1607 and

[7] After studying Confucian classics for years, the candidates competed for the three hierarchies of exam degrees sequentially: 1) the licentiate degree of *shengyuan* or Bachelor upon passing the entry exam held at the county level, 2) the *juren* or Master upon passing the provincial exam, and 3) the highest qualification of *jinshi* or PhD upon passing the national exam held at the imperial capital. The *juren* and the *jinshi* holders were qualified to get an official appointment in the imperial bureaucracy.

1610 (Bray 2013).

Xu Guangqi was by no means an exception among the Chinese literati. In fact, many other Ming and Qing scholars who were students of Confucian classics, such as Li Zhizao (1565-1630), Wang Zheng (1571–1644), and Dai Zhen (1727–1777), all embraced European science after coming into contact with the Jesuits (Tsien 1954).

### 2.3. The Settlement Pattern of the Jesuits

Despite their religious enthusiasm, the Jesuits found it difficult and hazardous to preach in China. When the Jesuits arrived in China, China was already a highly civilized empire with a sophisticated bureaucratic system and overwhelming Confucian orthodoxy. Moreover, China imposed a strict 'sea ban' policy that prohibited the contact between Chinese and foreigners. The only foreign exchange was restricted to the so-called tributary system, in which only designated Asian states were allowed to pay tributary visits to China periodically. As a result, the imperial authority of China was hostile to the unacquainted Europeans. Whether and when the Jesuits could enter a Chinese city largely depended on the occurrence of coincidences: it would be a coincidence if they could meet a Chinese official friend who was willing to personally provide help and protection (Brockey 2007).

To confirm the 'haphazard' pattern of the Jesuits' expansion, we checked the records from the Jesuits' diaries (Ricci and Nicolas 1615) and historians' studies (Brockey 2007) in terms of the specific means by which the Jesuits entered Chinese prefectures. There were 20 prefectures that had the pertinent records. We have displayed the locations of these prefectures with brief illustrations of the Jesuits' entrance to each of them in Appendix Figure A4. The records show that the Jesuits entered all of these 20 prefectures by chance. It is important to note that these 20 prefectures were the major Jesuit residences, accounting for 68% of the total number-years of the Jesuit presence in China between 1580 and 1820.

Of course, we should be aware that the distribution of the Jesuits in China may not be completely random. The Jesuits may still have had some choices in the location and time of their residences. They probably tended to live in big cities where there were more literati to preach to. To address this concern, we controlled for the possible factors that may affect the locational choice of the Jesuits, which is introduced in Section 3.3.

## 3. Data

The sample regions are the 252 prefectures in the 19 provinces of China Proper in the Ming and Qing dynasties. The period of analysis is 1500-1840. The reference period of 1500-1561 is when the Jesuits had not yet come to China. The treatment period is 1562-1840, which covers the whole course of the Jesuit mission in China.

The post-1840 period is excluded for the following reasons. Firstly, the channels of European knowledge diffusion to China became complicated after 1840. Upon being defeated by Britain in the first Opium War (1839-1842), China was forced to open its doors to the West. European knowledge was also diffused to China through translation, modern schools, hospitals, press, and modern firms, among others (Bai and Kung 2015). Before 1840, however, the Jesuits were the only intermediary of knowledge exchange between China and Europe. Secondly, the introduction of Western knowledge to China after 1840 was highly endogenous. For the purpose of "self-strengthening", Chinese elites deliberately translated Western books and introduced new technologies to industrialize China. Before 1840, European sciences were mainly diffused by the Jesuits for missionary purpose in China.

### 3.1. The Jesuits

In *The Répertoire des Jésuites de Chine de 1552 à 1800*, the Jesuit Joseph Dehergne had collected the biographies of all the 433 Jesuits sent to China. This is the most systematic record on Jesuits and their activities in historical China (Standaert 1991). Based on the time and place of every Jesuit's activities in China, we enumerated the total number of Jesuits in each prefecture over the decades.

Dehergne's data established that after the Jesuits were allowed to enter China in 1582, their missions in the mainland expanded continuously (Figure 1). By the 1710s, the number of Jesuits had reached the peak of 148. After the 1710s, the Jesuits began to decline in China because of the Chinese Rites controversy. In terms of regional distribution, the Jesuits missionized a total of 90 out of all the 252 prefectures (35%) of China Proper. A majority of the Jesuits resided in the lower Yangtze and the grand Beijing regions (Figure 2).

[Figures 1 and 2 about here]

We used the number of Jesuits in each prefecture in each decade as our primary measure of the Jesuits presence. To the extent that the Jesuits' knowledge diffusion may have had a long-term impact on Chinese scientific production, we also used the cumulative number of Jesuits-decades at the prefectural level as an alternative measure.

### 3.2. Chinese Scientific Production

To measure Chinese scientific production, we referenced the number of scientific works (book titles) written by Chinese scholars at the prefecture level in each decade. The Chinese literati had a culture of writing books and used this platform to publish their academic achievements. These works were recorded by a variety of historical collections, for instance, the local gazetteers and the official chronicles compiled by the imperial authorities. We obtained the list of Chinese scientific works from *Zhongguo Kexue Jishu Dianji Tonghui* (*Collections of Chinese Classics on Science and Technology*). Compiled by the Institute for the History of Natural Science of Chinese Academy of Sciences in 1994, the *Collections* includes a comprehensive record of all the important scientific works in Chinese history. A total of 482 book titles were recorded between 1500 and 1840. The topics included mathematics, astronomy, geography, agriculture, medicine, physics, chemistry, engineering (e.g. irrigation and military sciences) and general sciences (comprehensive volume). We only analyzed the books written by Chinese scholars, and excluded books written by foreigners, as well as the Chinese translations of foreign works.

We manually checked each author's biography and identified the author's place(s) of residence and the approximate period of publication. For books which have an indeterminate publication period, we reckoned it according to the year of the author's median age. On average, the median age of all the authors in our sample was about 35. This was equivalent to the average age of obtaining the *juren* or *jinshi* degree in *keju* exams (Elman 2000), which was the golden age of the literati's academic activities. Alternatively, we also used the author's death year to reckon the time of publication and found the results to be consistent (not reported). Based on the authors' places of residence and period of publication, we enumerated the number of book titles by prefecture and decade. To reduce the measurement error in the period of publication, we also organized the data on the 20-year or 40-year basis for robustness checks.

Certainly, the booklist in the *Collections* may not cover all the scientific works in Chinese history. For instance, books that may have been lost or not recorded in history, books that were never written since some scholars who did boast of scientific inventions were not known for their penmanship – such information was not available. There was also the challenge that the list did not provide the systematic information on the *quality* of the Chinese scientific works. Details such as content-sharing on the new or modern sciences in each book, and the literature's academic influence, were not observed. In other words, we can only measure the quantity of the Chinese scientific production.

The number of Chinese scientific works increased significantly after the Jesuits entered mainland China and began to diffuse European science in the 1580s (Figure 3). Before then (1500-1580), there were 4.4 titles of scientific works produced per decade. After the Jesuits' arrival (1580-1840), the average number of scientific works per decade increased substantially to 17. Moreover, the increase in scientific works was comparatively greater in prefectures where there were Jesuits. In prefectures with Jesuits, the average number of scientific works per decade increased by 235%, from 3.7 before 1580 to 12.4 thereafter. In prefectures without Jesuits, however, the average number of scientific works per decade increased by 187%, from 1.5 before 1580 to 4.3 thereafter, which is 26% less than that of prefectures with Jesuits.

[Figure 3 about here]

The increase in Chinese scientific works also varied by discipline (Appendix Figure A5). The most remarkable increase was in astronomy and mathematics. This corresponds to the fact that astronomy and mathematics were the primary knowledge that the Jesuits introduced to China. Between 1580 and 1840, Chinese scholars wrote 31 books on astronomy, while before 1580, China had not produced new astronomical works for centuries after Guo Shoujing's *Shoushi Li (Granting the Seasons)* in 1281. In mathematics, a total of 296 new books were written between 1580 and 1840. Measured on the decadal average, the number of mathematical works increased by 307% compared to that of 1500-1580. In addition, Chinese scientific production also achieved progress in most of the other scientific fields.[8]

The positive relationship between European knowledge diffusion and Chinese scientific production can also be gleaned from their geographical distribution. Figure 2 shows the distribution of the total number of Chinese scientific works produced from 1580-1840. A majority of works were produced at the Lower Yangtze delta and the grand Beijing area. These two areas were also important bases of the Jesuits' scientific activities (Elman 2005).

### 3.3. Control Variables

Although the Jesuits' entry to and exit from China were largely shaped by exogenous events, some local factors could have impacted the number of Jesuits who eventually stayed in China. We controlled for the following observables that may simultaneously affect both the

[8] In geography, for example, the average number of works per decade increased by 176% between 1500-1580 and 1580-1840. In the 17th century, the increase might be prompted by the introduction of Matteo Ricci's world map and the related geographical knowledge. In the 18th century, Chinese geographic research was further promoted by the King's Mathematicians' mapping in cartography in China (Elman 2005). See Appendix Figure A5 for the increase in the number of book titles in other scientific fields.

number of Jesuits and Chinese scientific production.

**Population**. From the 16th century, the Chinese population experienced explosive growth (Cao 2000). On the one hand, the increase in Chinese scientific works may simply reflect population growth. On the other hand, the Jesuits may have tended to choose the populous regions to missionize. To control for the possible effect of population, we constructed prefectural level population data based on Cao (2000, 2017). Based on the population records in local gazetteers, Cao estimated the population size of all Chinese prefectures for the time points of 1393, 1580, 1630, 1650, 1680, 1776, 1820, and 1851. We estimated the decadal population size between these time points using linear interpolation.

**Literati**. If the Jesuits stimulated the Chinese literati's interest in science, the number of literati would affect the number of Chinese scientific works. As educated elites in Ming-Qing China, the literati were scholars-officials conferred by the competitive *keju* exams.[9] We measured the number of literati using a prefecture's number of candidates who obtained the highest qualification of *jinshi* in each decade. Given the competitiveness of the *keju*, the *jinshi* holders were the cream of the crop from among the learned scholars. As the "upper-tail" human capital, the *jinshi* holders' cultural influence was the most far-reaching (Chang 1955; Ho 1962). For this reason, they were also the intellectual group that the Jesuits tried to cultivate. Of course, the *juren* holders were also knowledgeable and had contacts with the Jesuits. But there are no systematic records on *juren* between 1500 and 1840.

The data on the *jinshi* holders was obtained from Zhu and Xie's (1980) *Ming-Qing Jinshi Timing Beilu Suoyin (Official Directory of Ming-Qing Imperial Exam Graduates)*. It contains a complete list of all the 46,908 *jinshi* conferred in the Ming-Qing period. We enumerated the number of *jinshi* based on their birthplaces (or the places of examination in the event it differed from the birthplace) and the year of passing the *jinshi* exam.

Certainly, the number of *jinshi* may not fully capture the number of literati in a prefecture, because some *jinshi* would not stay in their home prefectures after getting an official appointment in other places. Having said that, the number of *jinshi* is arguably a valid *proxy* for the number of literati, in the sense that it reflects a prefecture's educational strength and academic success.

**Economic Prosperity.** The distributions of both the Jesuits and Chinese scientific production might be correlated with economic prosperity. Given that Ming-Qing China was an agriculture-dominant society, economic prosperity was largely determined by agricultural

[9] As the earliest meritocratic institution, *keju* was established during the Sui dynasty (581-618). From the Ming dynasty (1368) the exam system became fully institutionalized, and then lasted until 1905.

productivity. Given the lack of data on actual agricultural output, we used a prefecture's suitability for planting the prevailing major staple crops (wheat, rice, potatoes, and maize), to measure the potential agricultural productivity. The suitability of each crop is indexed according to a combination of climate, soil, and slope characteristics. The data was obtained from the Food and Agriculture Organization's (2002) Global Agro-Ecological Zones (GAEZ) database.

We also controlled for urbanization rate as an additional measure of economic prosperity. Urbanization rate was closely related with the level of commercialization in historical China (Skinner 1977). Moreover, most Jesuits and the Chinese literati tended to live in big cities, simply because the cities were political and cultural centers of imperial China. Urbanization rate was measured by the share of urban population in local prefectural population. This data was obtained from Cao (2017) and from our sample period, only the data from 1580 is available. We interacted the urbanization rate in 1580 with the decade dummies to capture the possibly changing effect of urbanization on the distribution of Jesuits and Chinese scientific production.

**Geographic Factors.** The Jesuits' locational choice in China might be shaped by certain geographic factors. The first is the distance to the coast, because coastal areas were economically prosperous in Ming-Qing China. To measure the distance to the coast, we calculated the shortest great-circle distance from a prefecture's centroid to the nearest point on the coastline.

In Ming-Qing China, the river was a major inland transportation conduit. By transporting books and letters, the river network diffused information and knowledge within China (Chen, Kung and Ma 2017). River access also affected the Jesuits' choices of residence. To facilitate communication and logistics, the Jesuits preferred to live in cities that were connected to the trunk of traffic. For example, the logistical supply from Macau could reach the Jesuits in mainland China through the dense river network in the south and the Grand Canal in the north plain (Brockey 2007). To measure the access to the river, we calculated the shortest great-circle distance from a prefecture's centroid to the nearest point on the major navigable river. The map of navigable rivers of Ming-Qing China was obtained from Harvard China Historical Geographic Information System (CHGIS).

In view of how it affected transportation and economic activities, terrain ruggedness may have shaped the regional distribution of the Jesuits and the Chinese educated elites. We controlled for the index of terrain ruggedness by calculating the difference in elevation between adjacent cell grids. The data was obtained from the United States Geographic Service

(USGS). Last but not the least, to control for the possible effect of prefecture size, we used the prefectural land area as the proxy.

We interacted all the above geographic variables with the decade dummies to capture their changing effect on the distribution of Jesuits and Chinese scientific production. The descriptive statistics of all the variables are reported in Appendix Table A2.

## 4. The Effect of the Jesuits on Chinese Science

To examine the effect of the Jesuits on Chinese scientific production, we began with the regression specification (1):

$$\text{Science}_{it} = a_i + \lambda_t + \mathbf{Jesuits}_{it} + \mathbf{X} + \varepsilon_{it} \qquad (1)$$

where $\text{Science}_{it}$ denotes the number of scientific works written by Chinese scholars at the prefectural level on a decadal basis. The variable of interest is $\mathbf{Jesuits}_{it}$ that measures the number of the Jesuits in each prefecture in each decade. Prefecture fixed effects ($a_i$) capture the time-invariant prefecture factors. Decade fixed effects ($\lambda_t$) capture the common shocks that may affect both the expansion of Jesuits and Chinese scientific production. $\mathbf{X}$ is a vector of controls that include the time-varying population size and number of Chinese literati, and the interaction terms between decade dummies and the time-invariant prefecture factors (urbanization rate 1580, agricultural suitability, distance to coast, distance to navigable river, terrain ruggedness, and prefectural land size).

The regression results are reported in Table 1. To provide a benchmark, column 1 only controlled for population size and the prefecture- and decade fixed effects. Column 2 controlled for Chinese literati measured by the number of *jinshi* degree holders. The results showed that the number of Chinese scientific works became significantly greater in the prefectures where there were more Jesuits. An additional Jesuit corresponded to an increase of 0.077 in Chinese scientific works. This is equivalent to a 138% increase in Chinese scientific works when evaluated at the mean (0.056). The number of Chinese scientific works was not affected by population size and the number of literati. This indicates that the increase in Chinese scientific production after 1580 was driven mainly by knowledge diffusion from Europe rather than by the endogenous human capital force of China.

[Table 1 about here]

To check whether the effect of the Jesuits on Chinese scientific production came from a prefecture's economic prosperity and geography, we interacted the decade dummies with urbanization rate, agricultural suitability, distance to coast, distance to navigable river, terrain ruggedness, and land area (column 3 of Table 1). Furthermore, we controlled for province-specific linear time trend to capture the possible effect of the inherent trend in China's scientific development (column 4).[10] The effect of the Jesuits did not change, suggesting that the effect of the Jesuits on Chinese science was not confounded by the effect of economic prosperity, geography, and the provincial inherent trend in scientific development.

The research period spans two dynasties, the Ming and the Qing. Both the Jesuit missions and Chinese scientific production may be affected by the different institutional environment between the two dynasties. To reduce the heterogeneity over time, we excluded the Qing period (1644-1840) and the years of social unrests near the end of the Ming dynasty (1630-1643). The effect of the Jesuits remains significantly positive (column 5 of Table 1).

There might be a lagged effect of the Jesuits on Chinese scientific production. Once European sciences were introduced to China, they would be kept, diffused, and persistently affect Chinese academia for a long period of time. For example, some translations of European sciences may have been reprinted after their first publications in China. Moreover, it may have taken time for Chinese scholars to learn the new knowledge and to adopt it to their own research work. To address this concern, we used the cumulative years of presence of all the Jesuits in a prefecture to capture the long-lasting effect of Jesuits in China. Reported in column 6 of Table 1, the cumulative number of Jesuits had a significantly positive effect on Chinese scientific production. This suggests that Chinese scholars could also have benefitted from the European science that was introduced in the past. But the coefficient of cumulative Jesuits, 0.003, is much smaller than that of the decadal measure of Jesuits, 0.078. This suggests that the personal contact with Jesuits may have played a more important role in promoting the Chinese scholars' scientific research.

### 4.1. Identifying Knowledge Diffusion: Jesuit Scientists versus Jesuit Priests

We then examined whether it was the Jesuits' knowledge diffusion rather than other correlates that promoted Chinese scientific production. For example, as Catholic activists, the Jesuits had distinct religious enthusiasm, entrepreneurship, and perseverance. These norms may have also influenced the Chinese literati's work ethic or academic ethos.

To identify the effect of knowledge diffusion, we disentangled the Jesuits who were in-

[10] Alternatively, we controlled for the interactions between the time trend and the prefectural factors (crop suitability, urbanization 1580, distance to coast, distance to river, terrain ruggedness, and land area). This did not change the effect of the Jesuits on Chinese science (not reported).

volved in scientific activities from those not in China and compared their differential impacts on Chinese scientific production. Scientific activities mainly included translating or compiling books of European sciences, introducing European inventions, and conducting scientific surveys, among others. Among the 433 Jesuits in China, 56 participated in scientific activities according to their biographies (Li and Zha 2002). They were defined as Jesuit scientists. The temporal change in the number of Jesuit scientists was consistent with historians' descriptions (Figure 4). For example, the Jesuits' first climax in scientific activities in China appeared in the early 17$^{th}$ century, the same period when most of the translation works were conducted (Tsien 1954). The second was during the late 17$^{th}$ and early 18$^{th}$ centuries, when the King's Mathematicians were sent to China. The other 377 Jesuits only did missionary work. We defined them as Jesuit priests. The number of Jesuit Priests was greater than that of Jesuit Scientists throughout 1560-1820 (Figure 4).

[Figure 4 about here]

If it was the Jesuits' introduction of European sciences that promoted Chinese scientific production, the number of Jesuit scientists should have a significantly positive effect on the number of Chinese scientific works. In contrast, the number of Jesuit priests should have no or much smaller effect on Chinese science. In this sense, the effect of Jesuit priests on Chinese science could be treated as a placebo test.

The validity of using Jesuit priests as a placebo is based on the reasoning that they were similar to Jesuits scientists in all respects of their China mission, except for the latter's introduction of European sciences. Specifically, both of them were European missionaries under the authority of the same Catholic order—the Society of Jesus. Both entered China in the 1580s, and were subject to the same temporal trend (and shocks) in the missionary expansion and decline in China (Figure 4). However, their geography distributions varied: the priests resided in 84 Chinese prefectures, which were much broader than the 34 prefectures in which the scientists resided (Figure 5). Even within the 30 prefectures where there were both priests and scientists, the numbers varied largely. This provided us with sufficient variations to compare the effects between Jesuit scientists and Jesuit priests on Chinese science.

[Figure 5 about here]

A remaining concern is whether the regional distributions of the Jesuit scientists and priests were subject to different prefectural factors in China. To examine this, we compared Jesuits scientists and Jesuit priests in terms of their prefectural correlates in Table 2 (columns 1 and 2). We regressed the numbers of Jesuits scientists and Jesuit priests on each of the prefectural observables between 1560 and 1820—the period of Jesuit presence in China. The prefectural observables include the average population between 1560 and 1820, total number of literati between 1560 and 1820, urbanization rate in 1580, agricultural suitability index, and geographic factors of distance to coast, distance to river, terrain ruggedness, and land area. In addition, to test whether the Jesuits tended to enter areas where there was a respect for science, we employ the number of Chinese scientific works before the Jesuit scientists came to China (1500-1580) as the proxy.

The results show that the regional distributions of both Jesuit scientists and Jesuit priests were not correlated with the measures of literati, economic prosperity, and geography. Moreover, their distributions were also not affected by a prefecture's scientific production before 1560. These results coincide with the historical anecdotes on the 'haphazard' pattern of the Jesuits' expansion in China (sub-section 2.3). The only observable factor that was significantly correlated with the distribution of Jesuits was population size. Moreover, population had a greater impact on Jesuit priests than on Jesuit scientists. That said, we can control for the population size to rule out its differential impacts on Jesuit scientists and Jesuit priests. Overall, there was no systematic difference between Jesuit scientists and Jesuit priests in terms of the determinants of their regional distributions.

Of course, given the limited historical information, we cannot rule out all the possible heterogeneities between the two Jesuit groups. For this reason, we treated the results of the placebo test as suggestive rather than conclusive.

[Table 2 about here]

Table 3 reports the differential impacts between Jesuit scientists and Jesuit priests on Chinese scientific production. Columns 1 and 2 show that the number of Jesuit scientists had a significantly positive effect on the number of Chinese scientific works. The effect was robust to the inclusion of economic and geographic factors. An additional Jesuit scientist would increase the number of Chinese scientific works by 0.235 or 420% when evaluated by the sample mean (0.056) of the number of Chinese scientific works. The large marginal effect of Jesuit scientists was reasonable, in the sense that a single Jesuit scientist could introduce much scientific knowledge and influence many Chinese scholars. Taking Matteo Ricci as an example, he translated as many as 20 European scientific books and introduced many European inventions to China, all while maintaining close relationships with a number of Chinese scholars in various key Chinese cities.

[Table 3 about here]

The number of Jesuit priests, however, had no effect on Chinese scientific works (columns 3 and 4 of Table 3). Furthermore, we ran a 'horse race' between the scientists and the priests, to examine their differential effects on Chinese scientific works in the same specification (columns 5 and 6). Jesuit scientists still had a significantly positive effect on Chinese scientific works, and the coefficient remains almost unchanged. Jesuit priests still had no effect on Chinese scientific works. These results indicate that the effect of the Jesuits on Chinese scientific production came from their introduction of European sciences in China.

To further rule out the possible violation of the unobserved prefectural factors on the results, we restricted the sample to the 90 prefectures where there were Jesuits between 1560 and 1820 (henceforth Jesuit prefectures). The reasoning is that, if the likelihood that the Jesuits could enter a prefecture was determined by certain prefectural factors, the effect of these factors would be largely ruled out after the non-Jesuit prefectures were removed from the sample. Indeed, within the Jesuit prefectures, the distribution of Jesuit scientists was not affected by the population size (columns 3, Table 2). Meanwhile, among the 90 Jesuit prefectures, only 34 had Jesuit scientists (Figure 5). This strikingly regional variation enabled us to examine the effect of Jesuit scientists on Chinese science within the Jesuit prefectures.

Table 4 reports the results using only the Jesuit prefectures. Jesuit scientists had a significantly positive effect on the number of Chinese scientific works. But Jesuit priests had no effect on Chinese scientific works. The coefficient of Jesuits scientists is almost identical to that of the full sample in Table 3. These results also indicate that the effect of Jesuit scientists was not biased by a large number of prefectures with zero Jesuits.

[Table 4 about here]

Furthermore, we used the cumulative years of presence of all the Jesuit scientists in a prefecture to capture the long-lasting effect of knowledge diffusion. Similarly, we also used the cumulative Jesuit priests as the placebo. Reported in columns 1 and 4 of Appendix Table A3, the cumulative Jesuit scientists had a significantly positive effect on Chinese scientific production. But the coefficient of cumulative Jesuit scientists, 0.012 (column 1), is much smaller than that of the decadal measure (column 6 of Table 3), 0.245. The results remained robust when we restricted the analysis to the Jesuit prefectures. As a placebo, the cumulative Jesuit priests had no effect on Chinese science.

To reduce the measurement error in the time of publication of Chinese scientific works, we aggregated the data to 20-year or 40-year (columns 2, 3, 5 and 6, Appendix Table A3). The results remained consistent with those of the decadal measures. Last but not least, given that the number of Chinese scientific works is a count variable, we used the conditional fixed-effects Poisson regression to check the robustness of the OLS estimates. This also alleviated the zero-inflated problem in the number of Chinese scientific works. The Poisson estimates are consistent with those of OLS (not reported).

### 4.2. Astronomy and Mathematics

Since a majority of the introduced European sciences was in astronomy and mathematics, the Chinese literati should have learnt and contributed more to these two subjects relative to the others in the Chinese context. To ascertain this, we divided the number of Chinese scientific works into two groups: one is the works in astronomy and mathematics, the other is the aggregation of works in agriculture, medicine, physics, chemistry, geography, engineering and comprehensive volume of sciences. We do not separate astronomy and mathematics because the boundary between the two subjects was not readily distinguishable at the time. For instance, the astronomical research mainly used mathematical method to make the calendar (Jami 2012).

The effect the Jesuit scientists had on astronomy and mathematics is greater than that on the other subjects (Table 5). This remained robust when we restricted the sample to only the Jesuit prefectures, used the cumulative measures of the Jesuits, and organized the data to 20-year or 40-year level (Appendix Table A4). Evaluated at the mean of the dependent variable, an additional Jesuit scientist would increase the number of Chinese astronomical or mathematical works by 257%, which was more than double of the effect of a Jesuit scientist on the other scientific subjects, at only 117%. This reinforced the main finding that it was the Jesuits' knowledge diffusion that stimulated Chinese scientific production.

[Table 5 about here]

### 4.3. Falsification Test on the Popular Literature

If the effect of Jesuit scientists on Chinese scientific production was driven by unobserved local economic or human capital factors, these factors should also be brought to bear in the book production of other fields. We conducted a falsification test using the number of novels (book titles) written by the Chinese as the dependent variable. Given that novels were mainly literary works in Ming-Qing China, the number of novels should be less likely affected by European sciences. Of course, the Jesuits also introduced European liberal arts, but most of which was religious works (Tsien 1954).

The data of novels is obtained from Chen Dakang's (2007) *Mingdai Xiaoshuo Shi* (*Histo-*

*ry of Novels in the Ming Dynasty*). It lists all the recorded novels written by the Chinese between 1368 and 1643. Based on the biography of the authors, we identified the place and time of publication of each novel.

Following the same strategy in analyzing Chinese science, we regressed the number of Chinese novels on the number of Jesuit scientists. For robustness, we first used the full sample prefectures before excluding the prefectures where there were no Jesuits. Reported in Table 6, Jesuit scientists had no effect on the number of Chinese novels. The result is robust to controlling for Jesuit priests and the other prefectural factors. Furthermore, we used the cumulative years of presence of all the Jesuit scientists in a prefecture to capture the long-lasting effect of knowledge diffusion, and aggregated the data to 20-year or 40-year to reduce the measurement error in the time of publication of Chinese novels. The results remained consistent with those of the decadal measures (Appendix Table A5).

[Table 6 about here]

This suggested that the increasing Chinese scientific works was triggered by the introduction of European sciences rather than by the unobserved correlates with the distribution of the Jesuits. Moreover, the results showed that the number of Chinese novels was affected mainly by population size, suggesting that the novels as popular literature primarily served the masses rather than the knowledge elites.

### 4.4. Regional Spillover

Over time, European scientific knowledge might be diffused to locations beyond the Jesuit scientists' residences, allowing the Chinese literati who did not have the opportunity to meet the Jesuit scientists to also access the European sciences. The diffusion was most likely through the translated books of European science, correspondence of letters, and the word-of-mouth publicity in the literati circle (Xiong 1994), although there are no systematic records on it. As a second-best alternative, we used a prefecture's shortest geographic distance to the nearest prefecture where there were Jesuit scientists as the proxy for the knowledge spillover.

The results showed that the distance to Jesuit scientists had no effect on Chinese scientific production (not reported). Given that the number of Jesuit scientists varied significantly across Chinese prefectures, maybe only the prefectures with considerable Jesuit scientists could have a spatial spillover. To address this concern, we used the distance to the prefectures where the total number of Jesuit scientists in 1560-1840 was over the median (3), but still did not find a significant effect of the distance on Chinese science. Of course, the results should be interpreted with caution given that the 'distance' measure of knowledge spillover was rough. It can only suggest that little European sciences were systematically spread from the Jesuit residence to the nearby places radially, but cannot deny the fact that some knowledge got diffused sporadically.

Instead, these results suggest that European sciences were mostly known to the local 'knowledge elites' circle in Ming-Qing China, and were less likely to be massively printed for commercial purpose as the popular books of literatures and Confucian classics. This is why the Qing scholar Liu Xianting (1648-1695) spent over 10 years to find Sabbatino de Ursis' (1575-1620) translation of European water conservancy, *Taixi Shuifa (Western Water Law)* (Zou 2011).

## 5. The Interaction between the Jesuits and the Literati

We have documented that the Jesuits promoted Chinese scientific production from 1580. Now we turn to examine the mechanism: whether the effect of the Jesuit scientists on Chinese science worked through their communication with the Chinese literati.

Figure 6 shows the prefectural distribution of literati measured by the total number of *jinshi* holders between 1500 and 1840. There were striking variations. For example, the lower Yangtze delta had produced the most *jinshi* holders, which is consistent with the historical fact that the region was the most culturally prosperous in Ming-Qing China (Elman 2000). Meanwhile, the distribution of Jesuit scientists covered both the prefectures with a strong presence of literati and those with a weak literati presence. This allowed us to examine the interactive effect between Jesuit scientists and Chinese literati on Chinese science.

[Figure 6 about here]

If the positive effect of Jesuit scientists on Chinese science worked through their contact with the Chinese literati, we should find that the effect of Jesuit scientists on Chinese science existed mainly in prefectures where there were more literati. In contrast, in areas with very few literati, Jesuit scientists should have had a very limited effect on Chinese science simply because of the lack of knowledge exchange between the two groups of intellectuals.

### 5.1. The Empirical Results

To examine this, we interacted the number of Jesuit scientists with the number of literati to capture the communication between the two intellectual groups in Chinese scientific production. Meanwhile, we interacted the number of Jesuit priests with the number of literati as a placebo. As before, we measured literati using the number of *jinshi* holders who were entitled in each prefecture in each decade. Of course, we reiterate that the number of *jinshi* may not fully capture the number of literati in a prefecture, because some *jinshi* would not stay in their home prefectures after getting an official appointment in other places. Here we use the number of *jinshi* as a proxy for the number of literati, in the sense that it reflects a prefecture's educational strength and academic success. To minimize the possible bias caused by the outliers in the number of *jinshi*, we took the natural logarithm of the number of *jinshi* plus 1, i.e., ln(*jinshi*+1). The regression specification is:

$$\begin{aligned}\text{Science}_{it} = a_i + \lambda_t + \mathbf{JesuitScientists}_{\boldsymbol{it}} \times \mathbf{Literati}_{\boldsymbol{it}} + \text{JesuitPriests}_{it} \times \text{Literati}_{it} \\ + \text{JesuitScientists}_{it} + \text{JesuitPriests}_{it} + \mathbf{X} + \varepsilon_{it} \qquad (2)\end{aligned}$$

The variable of interest is the interaction term $\text{JesuitScientists}_{it} \times \text{Literati}_{it}$. If the increase in Chinese scientific production was driven by the communication between the Jesuit scientists and Chinese literati, the coefficient of $\text{JesuitScientists}_{it} \times \text{Literati}_{it}$ should be significantly positive. As the placebo, the effect of Chinese literati on scientific production should be less likely affected by Jesuit priests, and the coefficient of $\text{JesuitPriests}_{it} \times \text{Literati}_{it}$ should not be significantly positive or much smaller than that of $\text{JesuitScientists}_{it} \times \text{Literati}_{it}$. $\mathbf{X}$ includes all the control variables ever used in Equation (1).

The results are reported in Table 7. We first examined the interaction between the literati and Jesuit scientists without controlling for the effect of Jesuit priests (columns 1 and 2). The independent effect of both the Jesuits and the literati on Chinese scientific works is insignificant, suggesting that the literati would be less likely to contribute to Chinese science if they could not access the new knowledge from the Jesuits. Likewise, the Jesuits alone would not directly promote Chinese scientific production without the effort of the Chinese literati. The two intellectual groups' contribution to Chinese science would only become feasible when they could interact with each other, as evidenced by the significantly positive coefficient of their interaction term.

In columns 3 and 4 of Table 7 we included in the regressions the interaction term between Jesuit priests and Chinese literati. The coefficient of their interaction term is insignificant. The interaction term between Jesuit scientists and Chinese literati remained significantly positive, suggesting that the Chinese literati's contribution to scientific works was stimulated by European scientific knowledge rather than by the preaching of the Jesuits. The results remained robust when we restricted the sample to the Jesuit prefectures only (columns 5 and 6).

[Table 7 about here]

For robustness, we also measured literati using the number of *jinshi* holders who were entitled in the recent 30 years. We chose 30 years because the average age of obtaining the *jinshi* degree was approximately 34, and the average life span of the literati was about 60-70 in the Ming-Qing period (Chang 1955; Elman 2000). In addition, we also measured literati using the total number of *jinshi* holders produced at the prefectural level between 1500 and 1580, i.e. the period before the arrival of the Jesuits. Doing so avoided the possible feedback effect from the Jesuits and Chinese science on the number of *jinshi* after 1580. Meanwhile, the prefectural number of *jinshi* in 1500-1580 captured a majority of variations in the prefectural number of *jinshi* in 1581-1820, simply because of the high persistence in the regional distribution of *jinshi* throughout the Ming-Qing period (Chen, Kung and Ma 2017). For instance, the correlation coefficient between the prefectural number of *jinshi* in 1500-1580 and that of 1581-1820 was as high as 0.82 at the 1% level of significance. The results using these two alternative measures of literati were robust (Appendix Table A6).

Since a majority of the Jesuits' sciences pertained to astronomy and mathematics, the Chinese literati should have learnt and contributed more to these two subjects relative to the others in the Chinese context. Indeed, we found that the effect of the interaction term between Jesuit scientists and literati on astronomy and mathematics was greater than that on the other subjects (columns 1 and 2, Appendix Table A7). As a falsification test, the interaction term between the Jesuit scientists and literati had no effect on the number of Chinese novels (column 3, Appendix Table A7). All of these results remained robust when we restricted the sample to the Jesuit prefectures only (columns 4-6, Appendix Table A7).

These findings coincide with historical anecdotes of the importance of Chinese scholars' scientific achievements upon meeting and interacting with the Jesuit scientists. Recall the cases of Xu Guangqi, Li Zhizao, and Wang Zheng in subsection 2.2 – they achieved remarkable scientific progress only after meeting and learning from the Jesuit scientists.

### 5.2. Why Confucian Literati Turned to Scientific Research?

There is no doubt that a scholar's scientific pursuit could be driven by his inherent curiosity in new knowledge. In any case, the degree holders selected from the highly competitive *keju* exams were the elites among the scholars in Ming-Qing China. They have been qualified for scientific research by their intelligence, literacy, and profound philosophical training over the years. Beyond their curiosity and qualification, the Chinese literati had also an inclination for studying science. The Jesuits' knowledge supply (partially) met the demand of the literati and provided them with a new way of pursuing success and fame via Western learning.

**Demand for Statecraft Knowledge.** Many administrative affairs in historical China required knowledge of science and technology. The emperors, for instance, needed astronomers and mathematicians to develop an accurate calendar (otherwise known as *nongli* or agricultural calendar); the latter was crucial for agricultural production, as well as to establish the emperor's legitimacy as the 'Son of Heaven'. The emperors also needed experts of topography to map the territories, and engineers for the production of clocks, glasses and other luxurious goods in the royal factories.

Likewise, local officials need to master a variety of practical knowledge for administrative purpose; these included bridge building, water control, famine relief, taxation, and military defenses, among others (Reynolds 1991; Schafer 2011). Officials who were capable in statecraft would undoubtedly be valued by the emperor. Chen Hongmou (1696-1771), for example, became an eminent official of the Qing dynasty for his remarkable achievement in managing agricultural technology, irrigation works, public finance and military logistics. He was appointed by the Qianlong emperor as the governor of more than nine provinces before being promoted to the Minister of Personnel (Rowe 2001).

Accordingly, unlike the conventional wisdom that China's civil exam only tested the candidates' mastery of Confucian classics, the *keju* exam never excluded science. In the provincial *juren* and national *jinshi* exams in the Ming-Qing period, the exam questions consisted of three sections. While the first two tested knowledge on Confucian classics, discourse and judicial terms, the third tested candidates on policy questions or *Cewen*, which required the candidates to write essays on a variety of statecraft issues. Many policy questions pertained to sciences. The topics included Natural studies (*gezhi*), Geography (*dili*), and Military matters (*bingshi*), among others.[11] The remaining also pertained to concrete knowledge, including Economy (*licai*), Classical studies (*jingxue*), Local governance (*lizhi*), World-ordering (*zhiguo*), Law (*xingfa*), and People's livelihood (*minsheng*) (see, Elman 2000, p. 721). To answer these questions, candidates had to master a broader and profound concrete

[11] Natural studies, or *Gezhi*, usually include the topics of astrology, calendrical studies, mathematics, and harmonics, among others. Based on the *Jinke Quanti Xince Facheng* (*Complete Models for Answers for New Policy Questions in Recent Provincial Civil Examinations*) compiled by the Qing scholar Liu Tanzhi in 1764, these science-related topics accounted for 21% of a total of 70 imperially selected policy questions in the provincial exams in 1756 and 1762 (Elman 2000).

knowledge beyond the scope of Confucian classics (Jiang and Kung 2018).[12]

**The Market of Professional Scholars.** Another possible motivation behind the Chinese literati's scientific pursuit may stem from the slim chance of upward social mobility through *keju* exams. During the Ming-Qing period, an average of 1,250 *juren* would be selected from 20,600 *shengyuan* candidates in each exam, and a further 220 *jinshi* would be selected from this pool of 1,250 *juren*. Accordingly, the likelihood that a *shengyuan* candidate could become a *juren*—the passport of entering government—was merely 6%, and that a *shengyuan* could eventually become a *jinshi* was only 1% (Chen, Kung and Ma 2017).[13] Moreover, competition had intensified over time given the increase in population size from approximately 170 million in the 1580s to 430 million in the 1850s (Cao 2017). Hence, the estimated number of examinees increased largely, with little change to the admission quota (Ho 1962). A student could not achieve the highest *jinshi* degree until the age of 34 on average, after painstakingly studying and repeatedly sitting for the exams for more than 20 years.

To make matters worse, candidates found it difficult to obtain a government appointment even after passing the exam simply because the number of degree holders had largely exceeded bureaucratic demand. In the 18th and 19th centuries, only about 5% of the qualified degree holders (*juren* and *jinshi*) could obtain government appointments. Even the *jinshi* holders had to wait for years before receiving a government appointment (Wakeman 1975).

As a result, *keju* exams in fact created a large literate group outside the bureaucracy. The educated elites had to pursue alternative outlets for fame and fortune (Elman 2000). Many scholars chose to continue their research careers. They competed for teaching and research positions in the academies, officials' private advisory body, and governments' book compilation projects, among others, or competed for academic sponsorship from the government and merchants.[14] Others chose to be lawyers, merchants, doctors, and publishers, and

[12] Even the Confucian classics are not merely all moral philosophy and literary grace. In fact, some classics also contain sophisticated natural philosophy. For example, the Qing mathematicians found the connections between the classics *Yi Jing* (*Book of Changes*) and European mathematics (Hsiao 2014).

[13] There are no records on the number of exam participants in the Ming-Qing period. Based on rough estimates, the percentages of candidates who obtained the *shengyuan*, *juren* and *jinshi* qualifications in the early 18th century were 5%, 0.3% and 0.053%, respectively (Chen, Kung and Ma 2017).

[14] In Ming-Qing China, officials often recruited scholars as their private consultants to help administrate a variety of public affairs; these included taxation, famine relief, developing local schools and libraries, and supervising engineering projects, among others. They also sponsored purely academic research to win reputation. For instance, as provincial governor of Jiansu, Song Luo (1634-1713) became eminent because he financed many scholars and built libraries (Elman 2005). For governments' book compilation projects, these mainly included the compilation of the chronicles, collections, and

experts in other professions (Nivison 1966; Peterson 1979; Chang 1962). Only the renowned scholars, in particular those with new and concrete knowledge, could be competent in this market of scholars. Mei Wending (1633-1721), for example, had no official position, but was highly praised and sponsored by the Kangxi emperor for his renowned accomplishments in mathematics and astronomy (Elman 2005).

## 6. Science without Development

The remaining issue is the impact of the Jesuits' knowledge diffusion on China's economic development. According to historians' studies, despite the fact that the Jesuits had stimulated a revival of Chinese science, they had little impact on China's technological advancement and thereafter, economic development. This could be partially due to the limitations of the Jesuits' knowledge diffusion in China, and that the limitations were manifested in the following aspects.[15]

The first pertains to the scope of knowledge diffusion. The Jesuits aimed to cultivate the small circle of the Chinese elites, with the primary purpose of converting the elites to Catholicism. They did not develop schools and presses to disseminate science and technology to the masses as what their Protestants successors did during the late 19th and early 20th centuries. As a result, the Jesuits' sciences failed to challenge the orthodoxy of Confucian classics in Chinese intelligentsia, and scientific curriculum was not introduced in China's educational system. The already institutionalized and standardized Confucian classics still dominated the school curriculum and the exams (Rozman 1981).[16]

Instead, the Chinese literati of the 18th century had gradually absorbed the Jesuits' sciences, especially mathematics, into the Confucian classics. Their purpose was to recover the glory of Chinese mathematics through the textual or *kaoju* study of the ancient sages' classical antiquity, rather than applied mathematics in manufacturing, voyages, and experiments as performed by their European counterparts in the Age of Enlightenment (Bai 1995; Mokyr

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local gazetteers. For example, in the 17th and 18th centuries, the Qing court organized more than 150 titles of book compilation (Du 1971). The largest book project in Chinese history, the compilation of *Siku quanshu* (*Complete Library of the Four Treasuries*) organized by the Qianlong emperor between 1773 and 1803, employed more than 3,600 scholars and 3,800 clerks (Elman 1984).

[15] Why Ming-Qing China did not *endogenously* develop modern science and industrialization is beyond the scope of this paper. For this unsolved 'Needham Puzzle', see, for example, Needham (1969), Huff (1993), Lin (1995), and Mokyr (1990, 2017).

[16] In contrast, in the 18th century the universities of Western Europe had begun to teach sciences and mechanical principle and established specialized laboratories. Craftsmen could easily learn and apply these knowledge (Mokyr 2005).

2017).[17]

Second, the sciences introduced by the Jesuits were largely the classical natural philosophy rather than modern science. The Jesuits' astronomy was basically the Tychonic system. The restrictions of the Catholic Church had prevented them from fully introducing the discoveries by Copernicus and Galileo. When the uncensored version of Copernican theory finally reached China in the mid-18th century, Chinese scholars found it contradictory to the earlier Jesuits' version (Sivin 1995).

Likewise, the Jesuits' mathematics was basically the static geometric mathematics based on the Euclidean and Aristotle's natural philosophy. They did not introduce China to the revolutionary analytical geometry, dynamic calculus and mechanics which are the instruments of engineers (Elman 2005). The dissolution of the Jesuit order in 1773 finally ended this wave of Sino-West knowledge contact. China missed out on the learnings from the European mathematical frontier in the Newtonian century.[18]

The result is that the Jesuits' introduction of European sciences mainly impacted the academic interest of a small group of Confucian elites but failed to 'enlighten' the artisans and ultimately did not influence economic development. To test this, we measured economic development using population density as the proxy in the absence of more precise measures (e.g. commercialization, industrialization, and GDP) in pre-modern China. Specifically, we examined the impact of the Jesuits' knowledge diffusion on population density across Chinese prefectures in the 1840s, after controlling for the initial economic condition measured by the population density in 1580. To gauge the influence of the Jesuits' knowledge diffusion, we used the aggregation of the years of presence of all Jesuit scientists in a prefecture between 1580 and 1840 as the measure, reasoning that the prefectural variation in the Jesuits' intellectual influence was not only reflected by the quantity of the Jesuit scientists, but also the duration of their activities.

The results show that Jesuit scientists had no contribution to the increase in population density between 1580 and 1840 (columns 1 and 2 of Table 8). Furthermore, Chinese scientific

[17] Dai Zhen (1727–1777), for example, thought that without mathematical accomplishment one could not understand the chapters related to astronomy, calendar and engineering in the Confucian classics. As the most famous Qing mathematician, Mei Wending applied mathematics to the interpretation of the *li* or principle—the core concept of Confucian classics. His research focused on the comparative mathematics between China and Europe, aiming to prove that Chinese mathematics was not inferior to the European (Henderson 1984).

[18] Certainly, there was also the sporadic introduction of European technology to China. For instance, Chinese craftsmen learnt the skills of making clocks, glasses, and other products from the Jesuits in the palace and several big cities (Elman 2005).

works produced in this period, also had no impact on population density (columns 3-5). This finding suggests that the Jesuits' knowledge diffusion in China never gave rise to an industrial enlightenment movement, nor did it impact economic development, unlike what the scientific revolution and Age of Enlightenment had sparked in contemporaneous Europe. China's industrial enlightenment had to take a backseat till it was forced to open up after the first Opium War in the 1840s (Spence 1990).

[Table 8 about here]

## 7. Conclusion

The Jesuits introduced China to the European sciences from 1580. Both historical anecdotes and statistical evidences indicate that many Chinese literati, stimulated by the novel European sciences, deliberately learnt it from the Jesuits. They then devoted themselves to scientific research using these new methods to further the scientific knowledge in China's context. Correspondingly, Chinese scientific production increased significantly in the 17$^{th}$ and 18$^{th}$ centuries.

Although the Chinese scientific movement was small in scale and less revolutionary compared to that of contemporaneous Europe, it indicates that the Chinese literati in the Ming-Qing period did not lack an interest in science nor were they opposed to learning from the West. The alleged hampering effect of the *keju* exams and the associated Confucian culture on Chinese science may have been overstated. Instead, the exam system cultivated a large learned group outside the bureaucracy who contributed to China's scientific progress upon comprehension of the European frontier knowledge.

It is beyond the scope of the paper to examine the reasons why China did not appear to succeed in developing modern science and industrialization after the 14$^{th}$ century. However, the findings of the paper suggest that the reasons behind the Needham Puzzle may not lie in the Chinese scholars' lack of interest in science, but rather the lack of knowledge exchange with the West, among others. The triggering effect of the Jesuits on Chinese scientific production illuminates China's modern transition after the forced opening up to the West after the 1840s. From then, a new and more substantial wave of Western learning was diffused to China. How the Chinese literati responded to the new knowledge shock, and contributed to Chinese industrialization – that is the next research agenda.

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## Figures and Tables

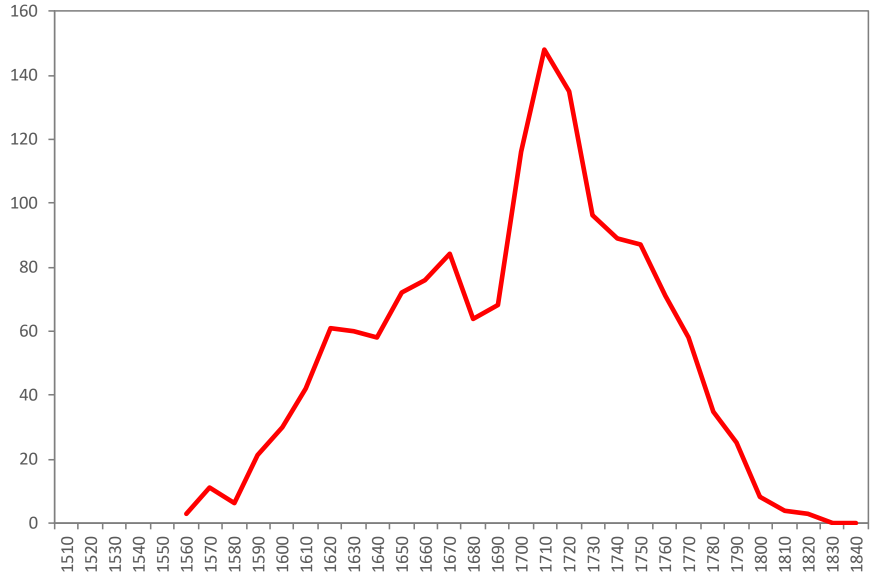


Figure 1. Number of Jesuits in China by Decade

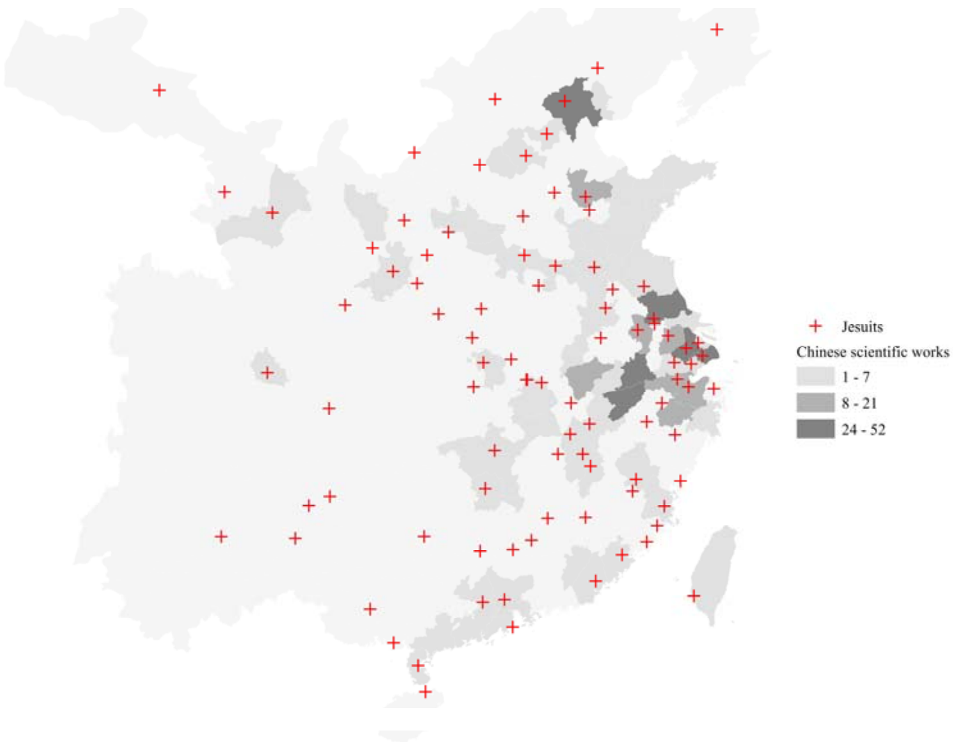

Figure 2. Distribution of Jesuits and Chinese Scientific Works, 1560-1840

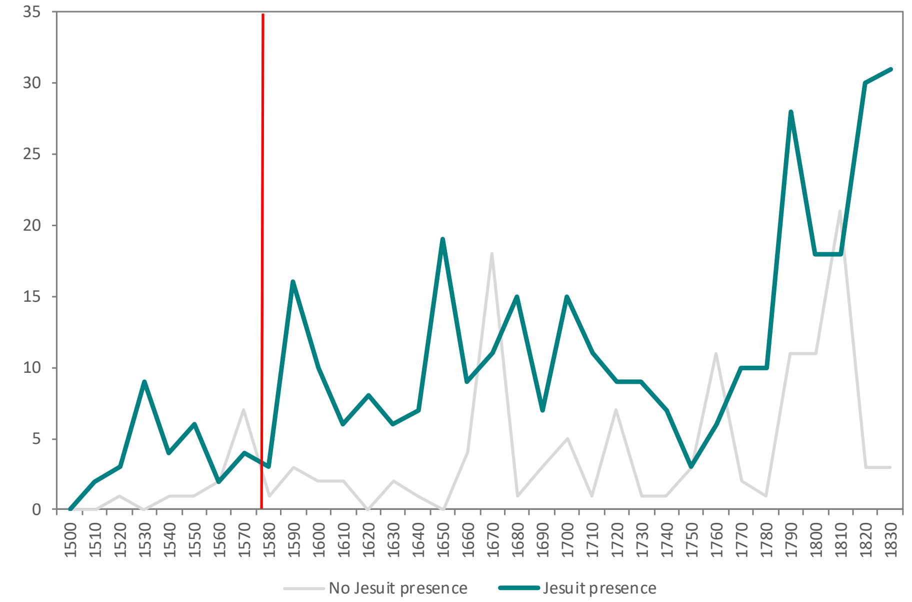


Figure 3. Number of Chinese Scientific Works (Book Titles)

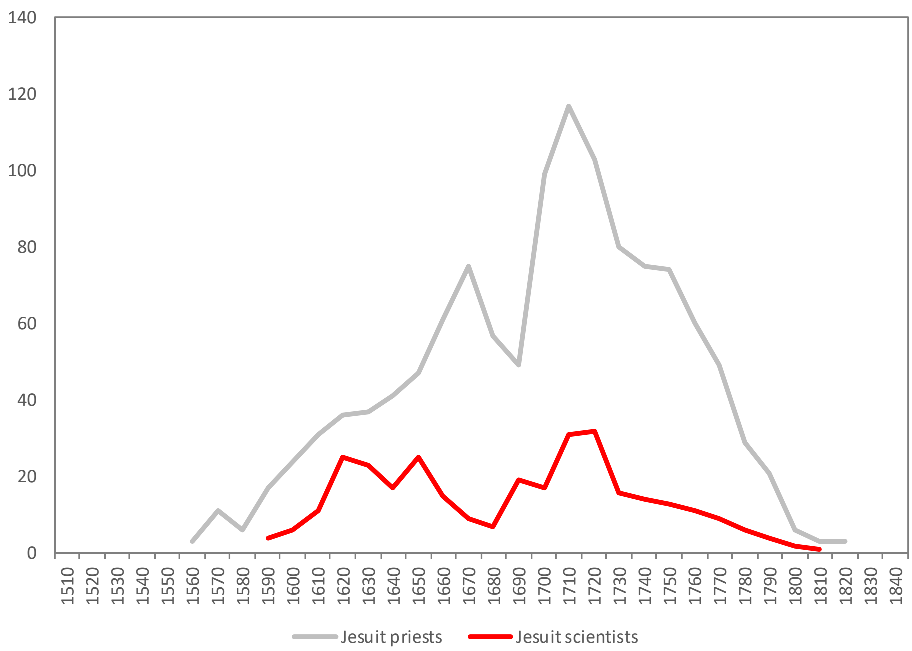


Figure 4. Numbers of Jesuits Scientists and Jesuit Priests in China, by Decade

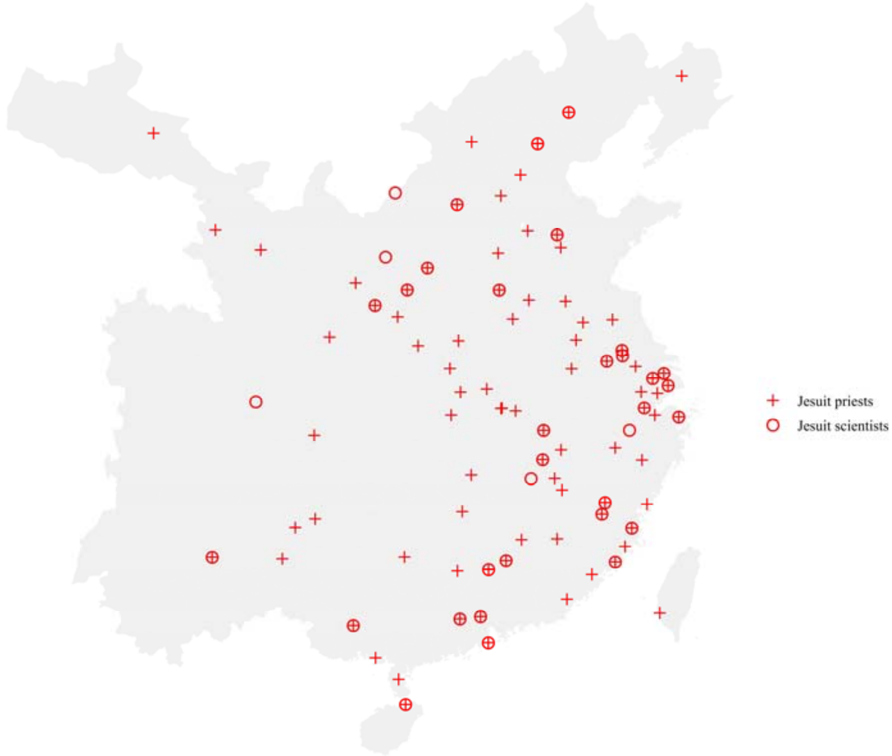


Figure 5. Distributions of Jesuits Scientists and Jesuit Priests in China


Figure 6. Distributions of Jesuit Scientists and Chinese Literati (*jinshi*) in 1500-1840

Table 1. The Effect of the Jesuits on Chinese Scientific Production

| | Dependent variable: number of Chinese scientific works | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Jesuits | 0.077** | 0.077** | 0.079** | 0.078** | 0.045** | 0.003*** |
| | (0.038) | (0.038) | (0.035) | (0.036) | (0.021) | (0.001) |
| Population | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Literati | | 0.001 | 0.001 | 0.001 | -0.001 | 0.001 |
| | | (0.003) | (0.003) | (0.003) | (0.004) | (0.003) |
| Prefecture factors × decade | | | Y | Y | Y | Y |
| Province-specific time trend | | | | Y | Y | Y |
| Observations | 8,568 | 8,568 | 8,568 | 8,568 | 3276 | 8,568 |
| R-squared | 0.026 | 0.026 | 0.026 | 0.057 | 0.050 | 0.046 |
| Number of prefecture | 252 | 252 | 252 | 252 | 252 | 252 |

Notes: All are OLS estimates with the prefecture- and decade fixed effects. In columns 1-5, Jesuits are measured by the number of Jesuits in each prefecture in each decade. Column 5 exclude the post-1630 period to rule out the Qing period (1644-1840) and the social unrests in the end of the Ming dynasty (1631-1643). In column 6, Jesuits are measured by the cumulative number of Jesuits in each prefecture since the first Jesuit arrived in there. Prefecture factors include agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 2. Correlations with the Distributions of Jesuit Scientists and Priests, 1560-1820

| | All prefectures | | Jesuits prefectures only | |
|---|---|---|---|---|
| | Jesuit scientists | Jesuit priests | Jesuit scientists | Jesuit priests |
| | 1 | 2 | 3 | 4 |
| Population | 0.002* | 0.007*** | 0.003 | 0.010*** |
| | (0.001) | (0.002) | (0.002) | (0.004) |
| Literati | 0.597 | 0.499 | 0.043 | 0.041 |
| | (0.527) | (0.667) | (0.035) | (0.032) |
| Agricultural suitability | -0.086 | -0.131 | -0.265 | -0.349 |
| | (0.077) | (0.128) | (0.245) | (0.369) |
| Urbanization 1580 | 0.315 | 0.433 | 0.507 | 0.610 |
| | (0.287) | (0.269) | (0.494) | (0.460) |
| Distance to coast | -0.001 | -0.0002 | -0.003 | -0.002 |
| | (0.001) | (0.001) | (0.003) | (0.004) |
| Distance to river | 0.004 | 0.004 | 0.015 | 0.016 |
| | (0.004) | (0.004) | (0.014) | (0.013) |
| Terrain ruggedness | 0.001 | 0.004 | 0.002 | 0.014 |
| | (0.001) | (0.003) | (0.003) | (0.012) |
| Land area | 0.000 | 0.000 | 0.0001 | 0.0001 |
| | (0.000) | (0.000) | (0.0001) | (0.0001) |
| Chinese scientific works 1500-1580 | 0.277 | 0.153 | -0.010 | -1.026 |
| | (0.625) | (1.200) | (0.789) | (1.772) |

Notes: All are OLS results of individual regressions at the prefectural level. The dependent variables are total number of Jesuit scientists or Jesuit priests at the prefectural level between 1560 and 1820. Columns 3 and 4 excluded the prefectures where there were no Jesuits throughout 1560-1820. Population is measured by average population between 1560 and 1820. Literati is measured by the total number of *jinshi* holders between 1560 and 1820. The results are robust to using the population size and literati around 1580, i.e. the approximate time before the arrival of the Jesuits. Chinese scientific works 1500-1580 is measured by the total number of Chinese scientific book titles produced between 1500 and 1580, which is used to capture the indigenous scientific tradition (or respect for science) before the arrival of the Jesuits. Robust standard errors are reported in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 3. The Effects of Jesuit Scientists and Jesuit Priests on Chinese Scientific Production

| | Dependent variable: number of Chinese scientific works | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Jesuit scientists | 0.235*** | 0.243*** | | | 0.235*** | 0.245*** |
| | (0.054) | (0.051) | | | (0.056) | (0.055) |
| Jesuit priests | | | 0.067 | 0.064 | -0.001 | -0.003 |
| | | | (0.047) | (0.041) | (0.018) | (0.021) |
| Population | Y | Y | Y | Y | Y | Y |
| Literati | Y | Y | Y | Y | Y | Y |
| Prefectural factors × decades | | Y | | Y | | Y |
| Province-specific time trend | | Y | | Y | | Y |
| Observations | 8,568 | 8,568 | 8,568 | 8,568 | 8,568 | 8,568 |
| R-squared | 0.036 | 0.068 | 0.017 | 0.049 | 0.036 | 0.068 |
| Number of prefectures | 252 | 252 | 252 | 252 | 252 | 252 |

Notes: All are OLS estimates with the prefecture- and decade fixed effects. Jesuit scientists are measured by the number of Jesuits who had scientific activities in a prefecture in a decade. Jesuit priests are measured by the number of Jesuits who had no scientific activities but preached only in a prefecture in a decade. Prefectural factors include agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 4. The Effects of Jesuit Scientists and Jesuit Priests on Chinese Scientific Production: Only Prefectures Where There Were Jesuits in 1560-1820

| | Dependent variable: number of Chinese scientific works | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Jesuit scientists | 0.242*** | 0.247*** | | | 0.239*** | 0.243*** |
| | (0.055) | (0.053) | | | (0.057) | (0.058) |
| Jesuit priests | | | 0.073 | 0.067* | 0.004 | 0.004 |
| | | | (0.047) | (0.036) | (0.017) | (0.023) |
| Population | Y | Y | Y | Y | Y | Y |
| Literati | Y | Y | Y | Y | Y | Y |
| Prefectural factors × decades | | Y | | Y | | Y |
| Province-specific time trend | | Y | | Y | | Y |
| Observations | 2,992 | 2,992 | 2,992 | 2,992 | 2,992 | 2,992 |
| R-squared | 0.066 | 0.138 | 0.036 | 0.111 | 0.066 | 0.138 |
| Number of prefectures | 88 | 88 | 88 | 88 | 88 | 88 |

Notes: All are same as those of Table 3 except that prefectures where there were no Jesuits throughout 1560-1820 were excluded. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 5. The Effects of Jesuits on Chinese Scientific Production: by Subjects

| | All prefectures | | Jesuit prefectures only | |
|---|---|---|---|---|
| | Astronomy and Mathematics | Other Subjects | Astronomy and Mathematics | Other Subjects |
| | 1 | 2 | 3 | 4 |
| *Mean of dep. vars.* | *0.040* | *0.015* | *0.079* | *0.035* |
| Jesuit scientists | 0.203*** | 0.042*** | 0.203*** | 0.041*** |
| | (0.045) | (0.011) | (0.048) | (0.012) |
| Jesuit priests | -0.003 | 0.0001 | 0.003 | 0.002 |
| | (0.017) | (0.006) | (0.019) | (0.005) |
| Observations | 8,568 | 8,568 | 2,992 | 2,992 |
| R-squared | 0.063 | 0.048 | 0.134 | 0.096 |
| Number of prefectures | 252 | 252 | 88 | 88 |

Notes: Astronomy & Mathematics denotes the total number of book titles on astronomy and mathematics per prefecture per decade. Other Subjects refer to the total number of book titles on geography, agriculture, physics, chemistry, medicine, technology and others per prefecture per decade. All are OLS estimates, and have controlled for population, literati, the prefecture- and decade fixed-effects, province-specific time trend, and the interaction terms between decade dummies and prefectural factors (agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area). Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 6. The Effects of Jesuits on Chinese Novels

| | Dependent variable: number of Chinese novels | | | | | |
|---|---|---|---|---|---|---|
| | All prefectures | | | | Jesuit prefectures only | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Jesuit scientists | 0.050 | 0.028 | 0.043 | 0.022 | 0.014 | 0.012 |
| | (0.090) | (0.082) | (0.088) | (0.081) | (0.088) | (0.088) |
| Jesuit priests | | | 0.016 | 0.012 | | 0.004 |
| | | | (0.054) | (0.048) | | (0.049) |
| Population | 0.0003*** | 0.0002* | 0.0003*** | 0.0002* | 0.0002 | 0.0002 |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0002) | (0.0002) |
| Literati | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 |
| | (0.006) | (0.005) | (0.006) | (0.005) | (0.007) | (0.007) |
| Prefecture factors × decades | | Y | | Y | Y | Y |
| Province-specific time trend | | Y | | Y | Y | Y |
| Observations | 3,528 | 3,528 | 3,528 | 3,528 | 1,232 | 1,232 |
| R-squared | 0.032 | 0.065 | 0.032 | 0.065 | 0.103 | 0.103 |
| Number of prefecture | 252 | 252 | 252 | 252 | 88 | 88 |

Notes: Chinese novels refer to book titles on novels written by Chinese in each prefecture in each decade between 1500 and 1640. All are OLS estimates with prefecture- and decade fixed-effects. Prefectural factors include agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 7. The Interactive Effect between the Jesuits and the Literati on Chinese Science

| | Dependent variable: number of Chinese scientific works | | | | | |
|---|---|---|---|---|---|---|
| | All prefectures | | | | Jesuit prefectures only | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Literati | -0.005 | -0.002 | -0.006 | -0.003 | -0.026 | -0.029 |
| | (0.011) | (0.014) | (0.011) | (0.014) | (0.027) | (0.028) |
| Jesuit scientists | -0.059 | -0.065 | -0.044 | -0.044 | -0.102 | -0.075 |
| | (0.125) | (0.115) | (0.133) | (0.127) | (0.109) | (0.122) |
| Jesuit scientists × Literati | 0.088*** | 0.093*** | 0.083*** | 0.086*** | 0.104*** | 0.093*** |
| | (0.028) | (0.026) | (0.032) | (0.031) | (0.026) | (0.030) |
| Jesuit priests | | | -0.016 | -0.024 | | -0.028 |
| | | | (0.017) | (0.025) | | (0.027) |
| Jesuit priests × Literati | | | 0.005 | 0.007 | | 0.012 |
| | | | (0.011) | (0.013) | | (0.014) |
| Prefecture factors × decades | | Y | | Y | Y | Y |
| Province-specific time trend | | Y | | Y | Y | Y |
| Observations | 8,568 | 8,568 | 8,568 | 8,568 | 2,992 | 2,992 |
| R-squared | 0.038 | 0.072 | 0.039 | 0.073 | 0.150 | 0.150 |
| Number of prefectures | 252 | 252 | 252 | 252 | 88 | 88 |

Notes: Literati is measured by the natural logarithm of the number of *jinshi* that a prefecture had produced in a decade plus 1, i.e. ln(*jinshi*+1). All are OLS estimates and have controlled for prefecture- and decade fixed-effects. Prefectural factors include agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 8. Jesuits, Chinese Science and Economic Prosperity

| | Dependent variable: population density in the 1840s | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Jesuit scientists | -5.073 | -6.928 | | | |
| | (4.022) | (4.208) | | | |
| Jesuit priests | 5.993 | -6.077 | | | |
| | (4.211) | (4.276) | | | |
| Chinese scientific works | | | 18.44 | | |
| | | | (16.90) | | |
| Chinese scientific works (astronomy and mathematics) | | | | 23.41 | |
| | | | | (17.29) | |
| Chinese scientific works (other subjects) | | | | | 58.08 |
| | | | | | (61.02) |
| Population density 1580 | 1.145*** | 0.829*** | 0.841*** | 0.840*** | 0.844*** |
| | (0.119) | (0.103) | (0.095) | (0.092) | (0.094) |
| Literati | | 2.528*** | 1.516*** | 1.531*** | 1.441** |
| | | (0.510) | (0.524) | (0.522) | (0.562) |
| Controls | | Y | Y | Y | Y |
| Observations | 252 | 252 | 252 | 252 | 252 |
| R-squared | 0.716 | 0.837 | 0.834 | 0.834 | 0.832 |

Notes: All are cross-prefecture OLS estimates. Jesuit scientists, Jesuit priests, and literati (*jinshi*) are aggregated at the prefecture level between 1560 and 1840. The controls are agricultural suitability, urbanization rate in 1580, distance to coast, distance to river, terrain ruggedness, and land area. Standard errors in parentheses are clustered at the prefectural level. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.