Knowledge Diffusion and Scientific Production: Evidence from the Jesuit Mission in Historical China

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Abstract

The Jesuits introduced European sciences to China from 1580. At the time, China was an autarkic civilization whose intelligentsia was dominated by Confucian literati. By making use of this knowledge supply shock, this paper examines the importance of knowledge diffusion in the production of new knowledge. Based on prefecture-level data on the distribution of the Jesuits and of Chinese scientific publications, this paper documents that the Jesuits stimulated scientific publications by Confucian literati. But this effect shrank after the Jesuits were expelled by the emperor of China in 1723.

Keywords: Knowledge diffusion; Science; Human capital; Jesuit mission; China; Europe
JEL Codes: N35; N75; O15; O33; Z12

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1. Introduction

Knowledge is an important engine for modern economic progress (Romer 1986; Mokyr 2002; Baten and van Zanden 2008; Dittmar 2011; Squicciarini and Voigtländer 2015). It is thus essential to understand the determinants of knowledge production. The production of new knowledge is built on existing knowledge. Accordingly, the access to existing knowledge, or more broadly an environment open to knowledge diffusion and exchange, may be crucial for the production of new knowledge (Eisenstein 1979; Weitzman 1998; Mokyr 2002).[1] But empirical evidence on this hypothesis remains scant, primarily because of the challenge in quantitatively gauging the specific, multi-dimensional channels of knowledge diffusion, let alone the reciprocal relationship between knowledge diffusion and knowledge production (Lucas 2009; Borjas and Doran 2012; Abramitzky and Sin 2014).

This paper examines the effect of knowledge diffusion on knowledge production in the context of the Jesuit mission to China in the 16th to 18th centuries. The Jesuit mission represents an exogenous knowledge supply shock to China. Under an autarkic regime, China's Confucian intelligentsia had little communication with the West until the Jesuits' arrival.[2] Thanks to their missionary enthusiasm, the Jesuits managed to enter China. To facilitate their missionary work, the Jesuits introduced European sciences to win over the Confucian literati—China's cultural-cum-political elites (Brockey 2007). The Jesuits thus ushered in the first wave of intellectual contact between the two different civilizations (Gernet 1985). This knowledge diffusion was sustained until the 1720s, when the emperors began to expel the Jesuits due to the Chinese Rites Controversy with the Pope. Another advantage of this historical context is that the Jesuit mission was the only intermediary of knowledge exchange between China and the West. This enables us to clearly measure the knowledge diffusion based on the distribution of the Jesuits.

This paper provides evidence that Chinese scientific production was stimulated by the Jesuits. To assess the effect of the Jesuits, I constructed a panel data of 254 Chinese prefectures between the years 1500 and 1840. Based on the biographies of all 433 recorded Jesuits who came to China, I identified their distributions at the prefectural level over decades. To identify that the effect of the Jesuits on Chinese science came from their introduction of European sciences, I distinguished the Jesuit

[1] For instance, the growth of the market for ideas was crucial for the Scientific Revolution and the Enlightenment in 16th- to 18th-century Europe (Mokyr 2002, 2005; Dittmar 2019). The interruption of access to frontier knowledge during World War I, however, reduced the production of basic science and new technologies (Iaria *et al.* 2018). See also Borjas and Doran (2012), F. Waldinger (2010, 2016) and Moser et al. (2014).

[2] This autarky started in 1368, when the Ming authorities imposed a strict 'sea ban' policy to crack down on foreign trade and communications. The autarky was sustained until 1842 when China was forced to open treaty ports to Western powers after being defeated by Britain.

scientists from the Jesuit priests. The Jesuit scientists refer to those Jesuits who were involved in scientific activities while they were preaching in China. The Jesuit priests refer to those Jesuits who did only missionary work. The Jesuit scientists and priests were similar in almost all aspects except for this difference in the spreading of science. I used the distribution of Jesuit scientists to measure knowledge diffusion, while the distribution of Jesuit priests was used as a placebo.

The regression results show that, during the period the Jesuits were in China (1581–1720), Chinese scholars in prefectures with Jesuit scientists wrote more works of science than those in prefectures without Jesuit scientists. There was no significant difference in Chinese scientific production between these two groups of prefectures prior to the arrival of these Jesuits. As a placebo, I look also at Chinese scientific production in prefectures with and without Jesuit priests. The presence of Jesuit priests had no effect on Chinese scientific production, suggesting that the effect of the Jesuits on Chinese science worked through the diffusion of European scientific knowledge. This mechanism is reaffirmed by the falsification finding that Jesuit scientists had no effect on the number of Chinese works on history and literature.

To address the endogenous distribution of the Jesuits in China, I control for a gamut of potential determinants of the Jesuits' distribution. These include economic conditions (population size, agricultural productivity and urbanization rate), the number of literati, and the geographic factors of distance to coast, distance to navigable river, ruggedness of terrain, and land area. In addition, I instrument the distribution of Jesuits using a prefecture's shortest distance to the early missionary route explored by the Jesuit pioneer Matteo Ricci during the years 1582 to 1601. By virtue of his outstanding communication skills and effort, Ricci successfully opened up a missionary route that connected the Jesuits' Asian base (Macau) to the imperial capital (Beijing). This route played an important role in directing the entry to and expansion in China of later Jesuits. Meanwhile, the distance to the Ricci route is arguably orthogonal to the correlates of Chinese scientific production after I rule out the effects of transportation, important cities along the Ricci route (Beijing and Nanjing), and other geographic factors. The instrumented estimation indicates a significantly positive effect of Jesuit scientists on Chinese scientific production.

My finding about the Jesuit effect on Chinese science is reinforced by the difference-in-differences estimation that exploits the prefectural variation in the timing of Jesuits' first entry. Historical narratives suggest that the time of Jesuit entry into a prefecture approximated a 'haphazard' pattern. Although the Jesuits may have tended to preach in prefectures with favorable economic conditions and a greater presence of elites, they could not decide the time of entry. Instead, when the Jesuits could enter a prefecture largely depended on coincidence. The results show that the number of Chinese scientific works increased after the 'entry shock' of the Jesuit scientist, whereas Jesuit priest entry has no effect on Chinese scientific works.

While the Jesuits stimulated a 'revival' of Chinese science after their arrival in

1580, this effect was not sustained due to the withdrawal of the Jesuits from China after the 1720s. The Chinese Rites Controversy over whether Chinese Catholics could worship ancestors (a traditional Confucian ritual practice) led several popes to rule against ancestor worship, and the Qing emperor Yongzheng began to expel and persecute the Catholic missionaries. The intellectual contact between China and Europe declined and was finally broken off after the Pope dismissed the Society of Jesus in 1773. Consequently, Chinese scholars lost the chance of learning from the European scientific frontier in the Newtonian century. Instead, their scientific research became—to borrow a term from Mokyr (2017)—"backward-looking", with an emphasis on rediscovering the glory of ancient classic antiquity by means of "textual studies" or *kaoju*, rather than applying science in experiment and industrial production, as their European counterparts did in the Enlightenment era (Elman 2005).

This paper contributes primarily to three strands of literature. The first pertains to the economics of knowledge diffusion. The findings of this study provide new historical evidence on the importance of knowledge diffusion (or idea flow) in knowledge production (Mokyr 2002, 2005; Borjas and Doran 2012; F. Waldinger 2010, 2016; Moser *et al.* 2014; Chaney 2016; Iaria *et al.* 2018; Dittmar 2019). More broadly, it also reinforces the importance of knowledge diffusion in human capital formation and economic development (Becker and Woessmann 2009; Dittmar 2011; Cantoni and Yuchtman 2014; Hornung 2014; Squicciarini and Voigtländer 2015; Dittmar and Seabold 2017; Becker *et al.* 2018; Giorcelli 2019).

Second, this study speaks to the literature on the positive role of historical missionaries in human capital formation and development in Latin America (M. Waldinger 2017; Valencia Caicedo 2018), in Africa (Nunn 2014; Wantchekon *et al.* 2015), and in Asia (Castelló-Climent *et al.* 2017; Calvi and Mantovanelli 2018; see also Valencia Caicedo 2019 for a summary), among other places. This study should be the first to quantitatively examine the human capital consequences of the Catholic mission in pre-industrial China. It illuminates the positive human capital outcomes of the Protestant missions in China after 1840 (Bai and Kung 2015).

Last but not the least, this paper shed lights on the Needham Puzzle (Needham 1969)—the mystery of China's failure to develop modern science and industrialization after the 14th century. The findings of this paper indicate the importance of the opening to (Western) knowledge flow in the history of China's scientific progress. Thus, the reason behind the Needham Puzzle may not have been, as conventional wisdom suggests, the Confucian literati's closed-mindedness or lack of interest in science, but more the lack of communication with the outside world under an autarkic regime.[3] This conclusion is reinforced by China's modern

[3] Certainly, this conclusion should be interpreted with caution in the sense that the Jesuit scientific influence in China was confined to only a small circle of knowledge elites rather than a

transition after it was opened up by the Western powers in the 1840s (Jia 2014; Bai and Kung 2015; Yuchtman 2017).

2. Historical Background

A European Catholic order, the Society of Jesus began its global mission in the mid-16th century. That Macau was occupied by Portugal in 1557 facilitated the Jesuits' expansion into East Asia. The Jesuits first arrived at Macau in 1562. Later, they were allowed by the local officials of Guangdong Province to enter mainland China in 1582. With the help of some Chinese officials, they managed to expand their mission northward. After they were allowed by the Ming emperor to reside in the imperial capital Beijing in 1601, the Jesuit mission in China stabilized and flourished (Brockey 2007). By 1700, their number had reached 128 (Figure 1). In terms of regional distribution, the Jesuits missionized a total of 90 out of the 254 prefectures (35%) of China Proper (Figure 2).[4]

[Figures 1 and 2 about here]

2.1. Jesuit Knowledge Diffusion in China

To facilitate their missions in China, the Jesuits sought the support of the literati. In communicating with the literati, Matteo Ricci (1552–1610) found that he was welcomed not because of his Catholicism, but because of his scientific knowledge and instruments. Ricci began to use the European sciences to cultivate the literati. Such novel, superior knowledge could attract the interest of these learned elites and help establish the prestige of the Catholic Church. Moreover, a unique feature of the Jesuits was their distinct academic qualifications. Most Jesuits were well-educated in science and philosophy. Prior to being sent to mainland China, the Jesuits also learnt the Chinese language and culture in academies in Rome, Portugal, or Macau (Xiong

scientific and industrial enlightenment that encompassed the mass of people. However, this still illuminates the comparison with contemporaneous Europe, where the knowledge elites (or "upper tail" human capital) played an important role in the development of modern science and industrialization (Mokyr 2002; Squicciarini and Voigtländer 2015). In addition, the findings of this paper also do not deny other institutional reasons for China's 'failure' in developing modern science and technology; for instance, the imperial examination system (Y. Bai 2019).

[4] Following the Jesuits, the Franciscans and the Dominicans also entered China in the early 17th century, but their activities were on a much smaller scale compared to those of the Jesuits. Unlike the Jesuits, who cultivated the Chinese elites, the Franciscans and the Dominicans targeted the grassroots. They did not diffuse science in China (Cui 2006). Unfortunately, there are no systematic records on the distributions of the Franciscans and the Dominicans in China. On a separate note, 'China Proper' refers to the territory included under the regular county-prefecture-province administration; it excludes many frontier areas.

1994). For these reasons, science became the principal instrument of the Jesuits' missionary expansion in China (Gernet 1985).

Between 1580 and 1800, the Jesuits translated over 130 European scientific titles into Chinese. The majority pertained to astronomy, followed by mathematics. The other titles were in physics, chemistry, biology, geography, medicine, and engineering, among other fields. Most translations introduced the scientific achievements that had arisen since the Renaissance (Tsien 1954). In astronomy, for instance, after the Chinese astronomer Guo Shoujing (1231–1316) published *Shoushi Li* (Seasons-Granting Astronomical System) in 1281, no new astronomical work was produced in China until the coming of the Jesuits three centuries later. By compiling *Tian Wen Lüe* (Summary of Astronomy) in 1615, Manuel Dias Júnior introduced Galileo's astronomy and his design for the telescope to China. 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' *Commentary on Euclid's Elements* into Chinese (*Jihe Yuanben*) in 1607. Clavius' *Commentary* was regarded by Chinese scholars as "the crown of Western studies" (Tsien 1954, p. 308).[5]

The Jesuits also introduced many European inventions and scientific instruments to China. For example, Ferdinand Verbiest (1623–1688) re-equipped the ancient observatory in Beijing with new celestial instruments from Europe. 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 for and admiration of the clocks. The Jesuits also brought with them many other novel things; these included the triple prism, microscope, thermometer, cannon, music box, globe, glasses, and other manufactured goods (Tan 2011).

From the early 1680s, the diffusion of European sciences to China reached new heights. This was largely due to the arrival of French Jesuits from the Royal Academy of Sciences in Paris. Upon the request of the Society of Jesus, King Louis XIV sent a total of 15 scientists, known as the King's Mathematicians, to aid the Jesuits' scientific activities in China (Jami 2012).The King's Mathematicians brought more than 30 new scientific instruments with them to China; these included 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

[5] As for geographical studies, by translating Abraham Ortelius' Theatre of the World in 1584 under the title Huanyu Gaiguan, Ricci acquainted the Chinese literati with the first modern world map and cartography. Likewise, another Italian Jesuit, Sabatino (Sabbathin) de Ursis (1575–1620), introduced Western hydraulic techniques to China in his book *Taixi Shufa* (Western Methods of Water Conservancy) in 1612. His *Yao Lu Ji* (Notes on Medicine) in 1617 was probably the first to systematically introduce Western pharmacology to China (Tsien 1954).

scholars mathematics and astronomy at the imperial palace, and assisted with the compilation of encyclopedias on these two subjects. A good example of their influence can be seen in the compilation of *Yuzhi Shuli Jingyun* (The Essence of Numbers and Their Principles) in 1722, which introduced the logarithmic table, the iterative method for higher-order equations, and the calculation of infinite series. This book influenced a number of Chinese mathematicians in the late 18th century (Du and Han 1992; Elman 2005).[6]

Relative to their success in knowledge diffusion, the Jesuits' missionary achievements are considered trivial. In the heyday of their China mission (around 1700), the total number of Chinese Catholic converts was alleged to be approximately 200,000 (Standaert 1991),[7] which accounted for merely 0.1 percent 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 14th century (Needham 1969). Instead, Confucian moral philosophy dominated the Chinese intellectual realm (Bol 2008). Meanwhile, China had become autarkic upon the establishment of the Ming dynasty in 1368, and hence China had little intellectual contact with the West before the arrival of the Jesuits. The Jesuits' introduction of European sciences gave the Chinese Confucian scholars a new impetus to learning and knowledge acquisition (Gernet 1985).

According to the conventional view of economic historians, living in an environment entrenched in conservative, Confucian traditions led Chinese scholars to have no interest in scientific research and Western learning.[8] The lack of interest may have been compounded by the incentive scheme under the imperial examinations. As a meritocratic institution, the examination system offered commoners a 'ladder of success' into the gentry class and officialdom. As a result, the imperial examinations absorbed talent into the study of Confucian philosophy for examination success rather than into scientific research. Such 'misallocation of

[6] Moreover, during their period of work in China, they kept in close contact with the scientific communities in Europe through continual correspondence. For instance, the Royal Society of London regularly delivered the periodical 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 instances of correspondence with Gottfried Leibniz (1646–1716) as part of their mathematical research exchange (Landry-Deron 2001).

[7] This is just rough estimation, as there are no systematic records on the number of Chinese converts.

[8] This is best summarized by David Landes (2006, pp. 11, 12, and 15): "[C]ultural triumphalism combined with petty downward 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."

talents' is deemed as one of the reasons behind the Needham Puzzle (Cipolla 1967; Needham 1969; Baumol 1990; Huff 1993; Lin 1995; Y. Bai 2019).

But many historical narratives suggest an opposite possibility. The introduction of the novel European sciences shocked China's Confucian literati. This stimulated the literati's curiosity for new knowledge. 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. Overall, China saw an intellectual wave that emphasized science and 'concrete learning' (*shixue*) from the late 16th century, though this movement was less revolutionary than that of contemporaneous Europe (Gernet 1985; Elman 2005).

A representative case is the relationship between Matteo Ricci and the Ming literatus Xu Guangqi (1562–1633). The chronological account of Xu Guangqi clearly demonstrates the change in his academic pursuits after coming into contact with Ricci. Through Ricci, Xu was able to appreciate the rationale and methodology behind European science. In the *Ke Tongwen Suanzhi Xu* (A Preface for the Publication of *Tongwen Suanzhi*),[9] Xu said:

> In addition to the discoursing on Catholicism, Father Ricci often taught me the principle of mathematics. His religiosity and reasoning are truthful and stripped of rhetoric. Just as leaves adhere to branches, his scholarship in astronomy and mathematics are solidly rooted in sound theoretical foundations. The truly well-rounded scholars like them are those who have been studying Western subjects for many years. Father Ricci and his colleagues' mathematical talents are many times those of their peers in the Han and Tang dynasties. We should all learn and benefit from their teaching (Xu 1963 [1619], p. 80).

Having recognized the lack of logical reasoning and the mathematical backwardness of Chinese science, Xu applied European sciences to the Chinese studies of mathematics, astronomy, agriculture, and military sciences. Between 1605 and 1633, he finished about 27 works on various sciences.[10]

Xu Guangqi was by no means an exception among the Chinese literati. In fact, many other Ming and Qing scholars who were students of the Confucian classics, such as Li Zhizao (1565–1630), Wang Zheng (1571–1644), and Dai Zhen (1724–1777),

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[9] *Tongwen Suanzhi* is a mathematical treatise by Ricci and Li Zhizao based on Christopher Clavius' (1585) *Epitome Arithmeticae Practicae* and published in 1614.

[10] Based on Tycho Brahe's (1546–1601) astronomical system, for instance, Xu compiled the encyclopedic *Chongzhen lishu* (Chongzhen Almanac) between 1629 and 1634, developing a new and more accurate calendar that is used to the present day. Another of Xu's important works 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.

all embraced European science after coming into contact with the Jesuits. They attempted to absorb European mathematical methods in re-constructing Chinese classical astronomy and mathematics and to apply scientific methods to study natural phenomena (Tsien 1954; Black 1989; Schafer 2011).[11] For example, in the monumental work on Chinese astronomy, *Lixiang Kaocheng Houbian* (Continuation to *An Investigation on the Calendar and Astronomy*), Giovanni Cassini's calendar calculation methods were emphasized (Gernet 1985).

Throughout this process, personal communication with the Jesuits was crucial to the scientific achievements of Chinese scholars, who received systematic, nuanced instruction in the novel European sciences from their Jesuit friends. This was especially true of the collaboration between Chinese scholars and the Jesuits that occurred as part of translation. To ensure their Chinese writings were acceptable, the Jesuits needed the aid of Chinese scholars. "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 literatus Wang Zheng became a renowned physicist because he could "learn from the three Jesuit teachers [Nicholas Longobardi, Johann Schreck, and Johann Adam Schall von Bell] day and night" (Zou 2011, p. 290). He even painstakingly learnt Latin from Nicolas Trigault in his fifties, when he already held a *jinshi* degree. Moreover, Chinese scholars learnt from the Jesuits' academic lectures and demonstrations of European inventions. As recorded in his diary, Ricci often attended gatherings of Chinese literati, who respectfully listened to Ricci's talks on Confucian classics and Western sciences (Ricci and Trigault 1983 [1615]).[12]

2.3. The Chinese Rites Controversy and the Retreat of the Jesuit Mission

After 1700, however, the Jesuits began to decline in China. The main reason was the Chinese Rites controversy, which lasted roughly from 1700 to 1775. The Popes Clement XI, Benedict XIV, and Clement XIV successively decreed that Chinese Catholics had to abandon the Confucian rites of ancestor worship since the latter constituted a religious rite that contradicted the Catholic faith. The Qing emperor Kangxi could not tolerate this stance and, after this diplomatic failure, he began in

[11] A case in point is Song Yingxing (1587–c. 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 classification and graphic notes. These technologies included European metallurgy, welding, and medicines, among others (Schafer 2011).

[12] The Jesuits aimed to cultivate the small circle of Chinese elites, with the primary purpose of converting them to Catholicism. They did not develop schools and presses to disseminate science and technology to the masses as their Protestants successors did during the late 19th and early 20th centuries.

1704 to restrict the Catholic missionary activities in China.

The adverse effect of the Controversy became substantial from 1723. In that year, the Yongzheng emperor (r. 1723–1735) ordered the Decree of Suppression, which forbade Chinese from accepting Christianity and began to expel missionaries. Consequently, the number of Jesuits in China plummeted (Figure 1). The prohibition of Christianity was sustained during the reign of the succeeding Qianlong emperor (1735–1795). 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).

The expulsion of the Jesuits undoubtedly interrupted the knowledge exchange between China and Europe. For instance, no further European mathematics was introduced into China after the mid-18th century. China missed the European discovery of dynamic calculus and engineering. Likewise, China's astronomical books in the 18th century were out of date by European standards (Elman 2005). Instead, the Chinese literati of the 18th century gradually absorbed the sciences learned from the Jesuits, especially mathematics, into the Confucian scholastic system (L. Bai 1995). Their purpose was to recover the glory of Chinese mathematics through the textual or *kaoju* study of the works of classical antiquity, rather than to apply mathematics in manufacturing, seafaring, and experiments as did their European counterparts in the Age of Enlightenment (Mokyr 2017).[13]

3. Data

3.1. The Jesuits

In his *Répertoire des Jésuites de Chine de 1552 à 1800*, the Jesuit Joseph Dehergne (1973) collected the biographies of all the 433 Jesuits sent from Europe to China. This is the most systematic record on Jesuits and their activities in China for that period (Standaert 1991). Based on the time and place of every Jesuit's activities in China, I enumerated the total number of Jesuits in each prefecture over the decades.

To identify the knowledge diffusion effect, I distinguish the Jesuits who were involved in scientific activities in China and those who were not. According to Li and Zha's (2002) collection of information on the Jesuits who made scientific contributions in Ming-Qing China, a total of 56 Jesuits participated in scientific activities; these included translating or compiling books about European sciences,

[13] For example, the most famous Qing mathematician, Mei Wending (1633–1721), applied mathematics to the interpretation of *li* or principle—the core concept of the Confucian classics. His research focused on comparing the mathematics of China and Europe, aiming to prove that Chinese mathematics was not inferior to the European (Henderson 1984).

introducing European inventions, and conducting scientific surveys, among others.[14] These 56 Jesuits are designated as Jesuit scientists (see the list in Table A1 of Online Appendix 2). The other 377 Jesuits only did missionary work and thus are designated as Jesuit priests.

The temporal change in the numbers of the Jesuit scientists and priests is consistent with historians' descriptions (Figure 3). As for the scientists, their first climax in China appeared in the early 17th century, the same period when most of the translations of works of European sciences were undertaken (Tsien 1954). The second was during the late 17th century, when the King's Mathematicians were sent to China. As for the priests, the temporal change in their numbers was consistent with that of the scientists, suggesting that their expansion and decline were subject to the same reasons (Figure 3).

The regional distributions of the two Jesuit groups are shown in Figure 4. The Jesuit priests resided in 84 (33%) Chinese prefectures, which represents a broader distribution than does the 34 (13%) prefectures in which the scientists resided. The striking regional variations allow us to compare the effect between Jesuit scientists and Jesuit priests on Chinese science. In the following empirical analysis, I will use Jesuit scientists to capture the knowledge diffusion effect, whereas Jesuit priests are used as a placebo test.

[Figures 3 and 4 about here]

3.2. Chinese Scientific Production

To measure Chinese scientific production, I 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 compilations, for instance, the local gazetteers and the official chronicles compiled by the imperial authorities. I obtained the list of Chinese scientific works from *Zhongguo Kexue Jishu Dianji Tonghui* (Collection of Chinese Classic Works in Science and Technology). Compiled by the Institute for the History of Natural Science of the Chinese Academy of Sciences in 1994, the Collection includes a comprehensive record of all the important scientific works in Chinese history. A total of 482 book titles

[14] Li and Zha's (2002) list of Jesuit scientists is mainly based on *Chouren Zhuan* (Biographies of Astronomers) written by the Qing scholar Ruan Yuan (1764–1849) and its continuation, *Xu Chouren Zhuan*, by the Qing scholar Luo Shilin (1783–1853). Ruan Yuan and Luo Shilin were well-known scientists at the time. They introduced all the Jesuit scientists and their scientific activities in China by carefully studying a variety of historical records in Ming-Qing period. I cross-checked the names of Jesuit scientists in Li and Zha (2002) with the biographies in Dehergne (1973), and identified the distribution of these scientists by prefecture and decade.

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. All the books included in the analysis are original works written by Chinese scholars. The Chinese translations of foreign works were excluded.

I manually checked each author's biography and identified the author's place(s) of residence and the approximate period of publication. For books that have an indeterminate publication period, I imputed it according to the year of the author's age at midlife.[15] Based on the authors' places of residence and period of publication, I counted the number of book titles by prefecture and decade. Certainly, the list in the Collection may not cover all the scientific works in Chinese history. For instance, it is possible that books may have been lost or not been recorded. There was also the challenge that the list did not provide systematic information on the *quality* of the works. Details such as content-sharing on the new or modern sciences in each book, and the influence of the work, were not observed. In other words, I can only measure the quantity of 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 5). Before then (1501–1580), there were on average 4.4 titles of scientific works produced per decade. After the Jesuits' arrival (1581–1840), the average number of scientific works per decade increased substantially to 17.

[Figure 5 about here]

The increase in Chinese scientific works also varied by discipline (Figure A1, Online Appendix 1). The most remarkable increase was in astronomy and mathematics. This corresponds to the fact that astronomy and mathematics were the primary type of 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. 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 percent as compared to that of the years from 1501 to 1580. In addition, Chinese scientific production also achieved progress in most of the other scientific fields.[16]

[15] On average, the age at midlife of all the authors in our sample was about 35. This was equivalent to the average age of obtaining the provincial-level (*juren*) or national-level (*jinshi*) degree in the imperial examinations (Elman 2000), which tended to be the highpoint of scholarly activity for literati. Alternatively, I also used the author's year of death to impute the time of publication and found the results to be consistent (not reported).

[16] In geography, for example, the average number of works per decade increased by 176% between the two periods from 1500 to 1580 and 1580 to 1840. In the 17th century, the increase

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 between 1581 and 1840. A majority were produced in eastern China, in particular the Lower Yangtze Delta region and the greater Beijing area. These two areas were also important bases of the Jesuits' scientific activities (Elman 2005).

3.3. Control Variables

I control for the following observables that may simultaneously affect both the distributions of Jesuits and Chinese scientific production.

Population. The number of Chinese scientific works may be correlated with local population size. Meanwhile, the Jesuits may have tended to choose the populous regions to missionize. To control for the possible effect of population, I constructed prefectural-level population data based on Cao (2000). Based on the population records in local gazetteers, Cao estimated the population size of all Chinese prefectures for the time points of 1393, 1580, 1680, 1776, 1820, and 1851. In the following panel data regressions, I estimated the decadal population (in units of 10,000) between these time points using linear interpolation.

Literati. Given that the Jesuits sought the help of the literati, they may have tended to preach in areas with more literati. On the other hand, as educated elites the literati also shaped China's scientific production. I measured the strength of literati presence using a prefecture's number of candidates who obtained the highest qualification of *jinshi* in the imperial examinations for each decade, and normalized it by prefectural population.[17] The data of *jinshi* was obtained from Zhu and Xie (1980). I enumerated the number of *jinshi* based on their birthplaces and the decade of passing the *jinshi* examination. Certainly, the number of *jinshi* may not fully capture the real number of literati in a prefecture, because some *jinshi* would not stay in their home prefectures after getting an official appointment. 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 examination 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 productivity. Given the lack of data on actual agricultural output, I used a prefecture's suitability for planting the prevailing major staple crops

might have been 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 China (Elman 2005).

[17] Of course, the provincial examination degree holders (*juren*) were also knowledgeable and had contacts with the Jesuits. But there are no systematic records on *juren* at the time.

(wheat, rice, potatoes, and maize) to measure its potential agricultural productivity.[18] I also controlled for the urbanization rate around 1580 as an additional measure of economic prosperity. Historically, the urbanization rate was closely related with the level of commercialization in China (Skinner 1977). Moreover, most Jesuits and Chinese literati tended to live in big cities, simply because the cities were political and cultural centers in imperial China. The urbanization rate was measured by the share of urban population in the local prefectural population. This data was obtained from Cao (2017).

Geographic Factors. The Jesuits' locational choices in China might have been 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, I calculated the shortest great circle distance from a prefecture's centroid to the nearest point on the coastline. Second, as a major form of inland transportation conduit in Ming-Qing China, rivers may have facilitated the Jesuits' missionary activities and knowledge diffusion. To measure access to rivers, I calculated the shortest great circle distance from a prefecture's centroid to the nearest point on a major navigable river.[19] Third, 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. I controlled for the index of terrain ruggedness by calculating the difference in elevation between adjacent cell grids.[20] Last but not the least, to control for the possible effect of prefecture size, I used the prefectural land area as a proxy.

The descriptive statistics of all the variables are reported in Table A2 of Online Appendix 1.

4. The Effect of the Jesuits on Chinese Science

4.1. Cross-Prefectural Evidence

The sample regions are the 254 prefectures in the 19 provinces of China Proper in the Ming and Qing dynasties. The period of analysis is 1501 to 1840.[21] To identify

[18] 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.
[19] The map of navigable rivers of Ming-Qing China was obtained from Harvard China Historical Geographic Information System (CHGIS 2016).
[20] The data was obtained from the U.S. Geographical Survey (1996).
[21] The post-1840 period is excluded for the following reasons. Firstly, before 1840, there was no institutional, cultural or economic change in China, which ensures a homogenous pre-industrial environment for us to examine the effect of the Jesuits on Chinese science. After 1840, China was forced to open up to the West and thus started its modern transition under Western influence. Second, the channels of European knowledge diffusion to China became complicated after 1840.

the effect of the Jesuits, I divide the period of analysis into three subperiods. The first is the pre-Jesuit period of 1501 to 1580, which is used to examine whether prefectures with Jesuits had already produced more scientific works before the Jesuits came to China relative to the prefectures without Jesuits. The second is 1581 to 1720, when the Jesuits entered mainland China and expanded their presence. The third is the post-Jesuit period of 1721 to 1840 when the Jesuits were gradually expelled from China following the Chinese Rites Controversy.

For each subperiod, I regress the total number of Chinese scientific works on the distribution of the Jesuits in the years between 1580 and 1720 at the prefectural level. To identify the knowledge diffusion effect of the Jesuits, I use the distribution of Jesuit scientists to measure the knowledge diffusion, whereas the distribution of Jesuit priests is used as the placebo. The specification is:

$$Science_i = a + JesuitScientist_i + JesuitPriest_i + \mathbf{X}_i + \varepsilon_i \tag{1}$$

where $JesuitScientist_i$ measures the cross-prefectural distribution of the Jesuit scientists. The primary measure is a dummy variable that indicates whether a prefecture had Jesuit scientists between 1580 and 1720 (hereafter, Jesuit scientist presence). In addition, to gauge the effect of the Jesuit scientists' number and duration of presence, I use the aggregation of the decades of presence of all the Jesuit scientists in each prefecture between 1580 and 1720 as an alternative measure (hereafter, Jesuit scientist number). $JesuitPriest_i$ denotes the distribution of Jesuit priests, which is measured by the dummy of presence or the aggregation of their number (and duration) at the prefectural level between 1580 and 1720. $\mathbf{X}_i$ is a vector of controls on prefectural characteristics; these include population size, number of Chinese literati (*jinshi*), urbanization rate at 1580, agricultural suitability, distance to coast, distance to navigable river, terrain ruggedness, and prefectural land size.[22]

Validity of the Placebo. The validity of using Jesuit priests as a placebo is based

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The channels ranged across translation, modern schools, hospitals, publishing presses, 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. Last but not least, 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 purposes in China. Macau was excluded from the sample as it had already been occupied by the Portuguese and had different institutions from mainland China.

[22] For population size, I use the population in 1580 for the period 1501 to 1580, the average population of 1580 and 1680 for the period 1581 to 1720, and the average population of 1776 and 1820 for the period 1721 to 1840. For the number of literati, I use the total number of *jinshi* per 10,000 population in the periods 1501 to 1580, 1581 to 1720, and 1721 to 1840, respectively. Logarithms are taken for all control variables except for agricultural suitability.

on the reasoning that they were similar to Jesuit 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 mainland China in the early 1580s and were subject to the same temporal trend (and shocks) in the missionary expansion and decline in China (Figure 3). Meanwhile, there are still sufficient variations in terms of their regional distributions for effective comparison (Figure 4).

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, I compared Jesuit scientists and Jesuit priests in terms of their prefectural correlates in Table A3 (columns 1 and 2) of Online Appendix 2. I regressed the numbers of Jesuit scientists and Jesuit priests on each of the prefectural observables in the period from 1581 to 1720. In addition, to test whether the Jesuits tended to enter areas where there was a respect or demand for science, I employ the number of Chinese scientific works before the Jesuit scientists came to China (1501–1580) as the proxy.

The results show that the regional distributions of both Jesuit scientists and Jesuit priests were positively correlated with population size and the number of literati. This is consistent with the Jesuits' missionary strategy in China: pursuing Chinese elites for help and protection. Their distributions were not correlated with most of the other prefectural observables. The only exception is distance to coast, which was negatively correlated with the presence of Jesuit scientists and priests. This is consistent with the fact that the economically prosperous areas of Ming-Qing China were mostly located along the coasts. Moreover, their distributions were not affected by a prefecture's scientific production before 1580. Overall, there was no striking difference between Jesuit scientists and Jesuit priests in terms of the determinants of their regional distributions.

Baseline Results. To provide a benchmark, I first examine the effect of Jesuit scientist presence on Chinese scientific production (Table 1). The regression analyses begin with controlling only for the (exogenous) geographic factors before including the (endogenous) population size, number of literati, and urbanization rate. Before the Jesuit scientists came to China (1501–1580), there was no significant difference between the prefectures with Jesuit scientists and those without them in terms of the number of Chinese scientific works (columns 1 and 2).

After the arrival of the Jesuits (1581–1720), prefectures with Jesuit scientists produced significantly more Chinese scientific works than the prefectures without Jesuit scientists (columns 3 and 4). On average, the difference in the number of Chinese scientific works is 1.705, which is substantial given that the mean of the number of Chinese scientific works in this period is only 0.73. After 1720, when the Jesuits were gradually expelled from China, prefectures where there had ever been Jesuit scientists still produced 1.248 more Chinese scientific works than the prefectures without Jesuit scientists. However, this difference is much smaller than that observed before 1723 and is not statistically significant, suggesting an adverse effect of the Jesuit retreat on Chinese scientific production (columns 5 and 6).[23]

[Table 1 about here]

The presence of Jesuit priests had no impact on the composition of Chinese scientific works (columns 1–3, Table 2). Furthermore, I ran a 'horse race' between the scientists and the priests, to examine their differential effects on Chinese scientific works in the same specification (columns 4–6). The presence of Jesuit priests still had no effect on Chinese scientific works. The effect of the presence of Jesuit scientists on Chinese science remains consistent with that of Table 1: insignificant before the Jesuits came to China, significantly positive after their arrival, and becoming insignificant after the Jesuits were expelled. Moreover, the coefficient of Jesuit scientist presence in each period remains almost identical with that of Table 1. These results indicate that the effect of the Jesuits on Chinese scientific production came from their introduction of European sciences in China.

[Table 2 about here]

Results within the Jesuit Prefectures. To further rule out the possible violation of the results by unobserved prefectural factors, I restricted the sample to the 81 prefectures where there were Jesuits between 1581 and 1720 (henceforth, Jesuit prefectures). I compared the 34 prefectures where there were Jesuit scientists with the other 47 prefectures where there were Jesuit priests but no Jesuit scientists in terms of Chinese scientific production. The reasoning for using this restricted sample 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 had little correlation with the prefectural observables (columns 3, Table A3 of Online Appendix 2).

Table 3 reports the results. Consistent with the full sample, prefectures with Jesuit scientists produced more Chinese scientific works than the non-Jesuit scientist prefectures did between 1581 and 1720, but not in the pre-Jesuit and post-Jesuit periods.

[Table 3 about here]

[23] Alternatively, the results are similar if using the years from 1771 to 1840 as the post-Jesuit period, as the Jesuit mission in China almost disappeared after the Pope finally dismissed the Society of Jesus in 1773.

Alternative Measure and Estimation Method. To capture the possible effect of the Jesuits' number and duration of presence in a prefecture, I use the aggregation of the decades of presence of all the Jesuit scientists in each prefecture between 1581 and 1720 as an alternative measure (Jesuit scientist number). The results are consistent with the dummy measure of Jesuit presence (Table A4, Online Appendix A2). Now an additional Jesuit scientist would increase the number of Chinese scientific works by 0.347 between 1581 and 1720 (column 2). This is translated to a 47.5 percent increase when evaluated by the mean (0.73) of Chinese scientific works. The results are similar when the analysis is restricted to the Jesuit prefectures only. The large marginal effect of Jesuit scientists is reasonable, in the sense that a single Jesuit scientist could introduce much scientific knowledge and influence many Chinese scholars. If we take 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 cities.

Given the large share of zero values in the dependent variable (92%, 85%, and 82% in the three periods, respectively), I use the negative binominal regressions to check the robustness of the OLS results (Table A5, Online Appendix A2). Panel A examines the effect of Jesuit scientist presence only; Panel B runs the 'horse race' between Jesuit scientists and Jesuit priests; Panel C restricts the analysis to the Jesuit prefectures only. The negative binominal estimates are consistent with those of OLS.

4.2. Instrumented Results

The foregoing analyses may still be confronted with the omitted variable bias. Some unobserved prefectural factors, such as a culture of openness or local gentry's attitudes towards missionaries, may simultaneously shape the distribution of Jesuits and the scientific production of Chinese literati. To address this concern, I use a prefecture's shortest great circle distance to the early missionary route explored by Matteo Ricci between 1582 and 1601 to instrument the prefectural distribution of the Jesuits.

Matteo Ricci. Matteo Ricci was the pioneer and early leader of the Jesuit China mission. The early missionary route taken by him played an important role in directing the entry and expansion of the later Jesuits. Despite their religious enthusiasm, the Jesuits found it difficult and hazardous to preach in China. At the time when the Jesuits arrived in China, China had imposed a strict 'sea ban' policy that prohibited contact between Chinese and foreigners. Foreigners were not allowed to live in China. By virtue of his outstanding communication skills and efforts, Matteo Ricci successfully entered China and established five missionary residences. He first arrived in Zhaoqing in Guangdong Province in 1582.[24] With the help of friends who were officials, Ricci successfully expanded the mission northward, and established new residences in Shaozhou in northern Guangdong (1589), Nanchang in Jiangxi Province (1595) and Nanjing in Nanzhili Province (1598), before he finally entered the imperial capital of Beijing in 1601. I connect these five residences using straight lines and refer to it as the Ricci route (Figure 6, a).[25]

After Ricci, the Jesuits entered China along the 'Ricci route'. This is because the Jesuits now had more information and knowledge about the places along the Ricci route. Moreover, thanks to the political connections that Ricci had cultivated, local officials and elites along the Ricci route were more likely to be hospitable to the missionaries who came after him. In particular, after Ricci was called by the emperor and was allowed to live in the imperial capital, Ricci won greater prestige among these local elites, and thus further facilitated the Jesuit mission in China (Ricci and Trigault 1983 [1615]; Brockey 2007).[26]

Along the Ricci route, the Jesuits managed to expand their mission to nearby regions (Figure 6, b-d). For example, around Nanjing, Lazzaro Cattaneo (1560–1640) established a new missionary station in nearby Songjiang (Shanghai) in 1608 with the help of Xu Guangqi, and then in Hangzhou three years later with the help of Li Zhizao and Yang Tingyun (1557–1627). Moreover, throughout the Jesuit era in China, the Ricci route performed the courier function of delivering information and logistical supplies from the Jesuits' Macau base to the inland missionary stations. For example, Nanchang in Jiangxi Province was a major transfer station for this purpose. Jesuit correspondence between Macau and the mainland missions was mainly delivered through Nanchang (Tang 2002). We thus expect a positive relationship between proximity to the Ricci route, on the one hand, and the presence of Jesuits, on the other.

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[24] Zhaoqing was the first Jesuit residence in mainland China. Its existence was indebted to another Jesuit pioneer, Michele Ruggieri (1543–1607). Thanks to his diplomatic efforts with the Guangdong governor-general, Ruggieri was allowed to live in Zhaoqing. He took Matteo Ricci to Zhaoqing in 1582 (Brockey 2007).

[25] Certainly, the actual route Ricci took did not necessarily follow a straight line. I use the hypothetical straight line to attenuate the effect of transportation.

[26] For example, when the Jesuit Jean de Rocha (1566–1623) entered Nanjing, Ricci had left Nanjing for Beijing. But Jean de Rocha was still welcomed and protected by the local officials. He said that the Jesuits' reputation among and relationship with local officials had been established by Ricci, and was crucial for the Jesuits' residence and development in Nanjing. Likewise, the Jesuit Alexandre Valignani (1538/9–1606) was aided in his China journey by Matteo Ricci, who had his friend, the official Xu Guangqi, write to the local officials along the route from Macau to Beijing to seek their protection and assistance for Valignani (Ricci and Trigault 1983 [1615]).

[Figure 6 about here]

I formally test the correlation between the distance to the Ricci route and the distribution of Jesuit scientists in the period from 1581 to 1720 in Table 4. One concern is that the Ricci route was located in eastern China. The distance to the Ricci route may just reflect China's striking east-west difference in scientific production (compare Figure 2 and Figure 6) rather than a real Ricci effect. To address this concern, I exclude the five provinces in western China: Gansu, Shaanxi, Sichuan, Guizhou, and Yunnan. By doing so, the effect of the distance to the Ricci route can be examined in a relatively homogenous sample region (Figure A2, Online Appendix 1). The distance is measured in kilometers (in logarithm). Consistent with historical anecdotes, distance to the Ricci route had a significantly negative effect on the presence of Jesuit scientists, whether or not I controlled for the other prefectural correlates (Table 4, columns 1 and 2).

The Ricci route passed through two important political-cum-academic centers in China—Nanjing and Beijing. To disentangle the effect of the Ricci route from the two cities' spillover effect on Chinese scientific production, I control for a prefecture's shortest distance to Nanjing and that to Beijing (Table 4, column 3). The effect of the distance to the Ricci route remained significantly negative. This result remains robust when the Jesuit scientist number is used as the dependent variable (column 4).

[Table 4 about here]

Exclusion Restriction. The distance to the Ricci route is arguably orthogonal to Chinese scientific production. The Ricci route did not pass through China's economic and cultural centers (besides Nanjing and Beijing). After controlling for the distances to Nanjing and Beijing, one sees the distance to the Ricci route has no correlation with a prefecture's initial economic condition as measured by population size in 1580 (column 1 of Table 5), nor with its cultural or academic strength as measured by the number of *jinshi* per 10,000 people in the period from 1501 to 1580 (column 2).

The validity of the instrument is substantiated by the reduced-form regressions of Chinese scientific works on the distance to the Ricci route (columns 3–5, Table 5). The distance to the Ricci route had no effect on Chinese scientific works before the arrival of the Jesuits (column 3), suggesting that the Ricci route did not play a role in knowledge diffusion. The distance to the Ricci route came to have a significantly negative effect on Chinese scientific works between 1581 and 1770, suggesting that the Ricci route promoted Chinese sciences through facilitating the Jesuits' expansion (column 4). After the Jesuits were expelled from China, the effect of the Ricci route on Chinese science disappeared (column 5).

Last but not least, a potential violation is that the Ricci route may capture the transportation effect. Indeed, the Ricci route was close to the major courier routes in

Ming-Qing China (Figure A3, Online Appendix 1). To rule out the possible effect from the transportation infrastructure, I run a 'horse race' between the distance to the Ricci route and a prefecture's shortest distance to the nearest courier route (Table 5, column 6). The distance to the courier route had no effect on the distribution of Jesuit scientists, whereas the effect of the distance to the Ricci route remains robust.

[Table 5 about here]

Instrumented Results. The two-stage least squares (2SLS) regression results are reported in Table 6. As with the OLS estimations, I first exclude the endogenous controls variables (population size, number of literati and urbanization rate) before fully including them into regressions. Jesuit scientist presence, which is predicted by the distance to Ricci route, had a significantly positive effect on Chinese scientific works during the Jesuit period (1581–1720) (columns 3 and 4). It had no effect on Chinese scientific works before the Jesuits came to China (1501–1580) (columns 1 and 2) or after the Jesuits were expelled (1721–1840) (columns 5 and 6). The instrumented effect of Jesuit scientist presence in the period from 1581 to 1720 became greater than that of the OLS estimate (1.705); prefectures with Jesuit scientists would produce 4.648 more books than prefectures without Jesuit scientists (column 4).

The results remain robust when the IV-Poisson estimation is used to address the zero inflation concern in the number of Chinese scientific works (columns 1–3 of Table A6, Online Appendix 2), or when Jesuit scientist number is used as an alternative measure of knowledge diffusion (columns 4–6 of Table A6, Online Appendix 2).

[Table 6 about here]

4.3. Difference-in-Differences Evidence

The Entry Effect. The timing of Jesuits' first entry varied across prefectures. In a difference-in-differences setting, this sub-section exploits the prefectural variation in the time of entry, and examines whether Chinese scientific works increased after the 'entry shock' of the Jesuit scientists. The specification is:

$$Science_{it} = a + JesuitScientist_{it} + JesuitPriest_{it} + \mathbf{X}_{it} + pref_i + decade_t + \varepsilon_i \quad (2)$$

The unit of observation is prefecture-decade. The period of analysis is 1501 to 1720. I exclude the post-1720 period in order to focus on the entry effect. $Science_{it}$ denotes the number of Chinese scientific works produced in each prefecture in each decade.

$JesuitScientist_{it}$ denotes the Jesuit scientist entry, which is a dummy variable that equals 1 for decades after the Jesuit scientists first entered a prefecture. $JesuitPriest_{it}$ denotes the Jesuit priest entry, which is a dummy variable that equals 1 for decades after the Jesuit priests first entered a prefecture. To avoid collinearity with the Jesuit scientist entry, I only count the Jesuit priest entry in prefectures without Jesuit scientists.

$\mathbf{X}_{it}$ refers to the time-varying controls. One is the decadal population at the prefectural level; the other the number of *jinshi* per 10,000 people produced in each prefecture in the past 30 years. Given that the average age of obtaining the *jinshi* degree was approximately 34, and the average life span of the literati was about 60 to 70 in the Ming-Qing period (Chang 1955; Elman 2000), the cumulative number of *jinshi* over the past 30 years could approximately capture the number literati in a prefecture. The logarithm is taken for both controls. After controlling for the prefectural fixed-effects ($pref_i$), the time-invariant prefectural determinants of the Jesuit distribution are ruled out. The effect of common shocks faced by all prefectures are absorbed by the decade fixed-effects ($decade_t$).

Historical narratives suggest that the time of Jesuit entry into a prefecture was random. Although the Jesuits may have tended to preach in prefectures with favorable economic conditions and a greater presence of elites, they could not decide the time of entry. Instead, when the Jesuits could enter a prefecture largely depended on coincidence (Brockey 2007).[27] For example, Matteo Ricci had been planning to establish a missionary station in Beijing. But he did not have an opportunity to do so until he met a prestigious eunuch in Nanjing who appreciated Ricci's talent. When he returned to Beijing, he took Ricci and recommended Ricci to the emperor in 1601. Likewise, Lazzaro Cattaneo could open the new mission in Songjiang only when his friend Xu Guangqi had to return to his hometown of Songjiang in 1608 to mourn his deceased father for three years according to Chinese custom (Ricci and Trigault 1983 [1615]).

To further confirm the 'haphazard' pattern of the time of entry, I checked the records from the Jesuits' diaries (Ricci and Trigault 1983 [1615]) and studies by historians (Brockey 2007) for the specific means of entry. There were 20 prefectures for which pertinent records were available. This is a representative sample in the sense that these prefectures were the sites of the major Jesuit residences, accounting for 68 percent of the total number-decade of the Jesuit presence in China between 1580 and 1820. The records show that the Jesuits entered all of these 20 prefectures by chance (Online Appendix 3). Of course, we cannot ensure that all the entries of the Jesuits were random events; they might also have been shaped by unobserved time-varying factors in the prefectures they wanted to enter.

[27] This coincides with the 'haphazard' pattern of the Jesuit entry to Latin American in the 17th century (Valencia Caicedo 2019).

The regression results on the entry effect are reported in Table 7. I first examine the Jesuit scientist entry without controlling for the Jesuit priest entry (column 1). After the Jesuit scientist entered into a prefecture, the number of scientific works produced in a prefecture per decade increased by 0.137. The increase is substantial in the sense that the mean of the number of Chinese scientific works (per prefecture per decade) between 1500 and 1720 is only 0.04. Column 2 runs the 'horse race' between Jesuit scientist entry and Jesuit priest entry. The positive effect of Jesuit scientist entry remains robust, whereas Jesuit priest entry has no effect on Chinese scientific works. I further restrict the regressions to the prefectures where there were Jesuits by 1720 (columns 3 and 4). The effect of Jesuit scientist entry remains significantly positive with little change in the magnitude of coefficient. Jesuit priest entry still has no effect on Chinese scientific works.

[Table 7 about here]

The Expulsion Effect. Likewise, the time of the Jesuits' retreat also varied across prefectures. After the Yongzheng emperor ordered the expulsion of Catholic missions from China, the retreat of the Jesuits followed a gradual process that was sustained until the late 18th century. Following the same strategy in examining the entry effect, I test whether Chinese scientific works decreased after all the Jesuit scientists retreated from a prefecture.

The Jesuits' retreat can also, arguably, be treated as an exogenous shock, simply because it was caused by the emperor's prohibition of Catholicism due to the Chinese Rites Controversy with the Pope (see sub-section 2.4). It was not initiated by the Jesuits or Chinese literati in each prefecture. Certainly, in a prefecture, when and to what extent the government implemented the emperor's decree of expulsion may have been shaped by some time-varying local factors. The most plausible one is the strength of the local literati, reasoning that they were the main protective force of the Jesuits in China.[28] This effect can be largely ruled out by controlling for the number of *jinshi*. On the other hand, the time and extent of expulsion in a prefecture may also have been subject to the turnover of local governors who had different attitudes towards the missionaries. Given this unobservable confounding factor, the coefficient of the expulsion may be biased and hence should be interpreted with caution.

The analysis is restricted to the period between 1701 and 1840, i.e., from a year when the Jesuit China mission was in its heyday to a year after all the Jesuits had retreated from China. I construct a dummy variable of Jesuit scientist expulsion,

[28] Indeed, even after the Yongzheng emperor's decree expelling the missionaries, some Jesuits were able to secretly stay in China with the help of their literati friends. For example, the Jesuit João Duarte (1671–1752) managed to stay in Hunan Province till 1740 (Brockey 2007).

which equals 1 for the period after all the Jesuit scientists had left at the prefectural level. In the same way, I construct a dummy variable of Jesuit priest expulsion as the placebo. The results are reported in Table 8. After the Jesuit scientists were expelled, the average number of Chinese scientific works per prefecture per decade decreased by 0.354 (column 1). Jesuit priest retreat had no effect on Chinese scientific works (column 2). These results remain similar when I restrict the sample to the Jesuit prefectures only (columns 3 and 4).[29]

[Table 8 about here]

4.4. Chinese Liberal Arts Works

If the effect of Jesuit scientists on Chinese scientific production was driven by unobserved local cultural or human capital factors, these factors should also be brought to bear in the book production of other fields. I conducted a falsification test using the number of book titles on two major fields of liberal arts in Ming-Qing academia, history and literature, as the dependent variable. Relative to the works on sciences, these liberal arts works should be less likely affected by European sciences. Of course, the Jesuits also introduced European liberal arts, but most of these were religious works (Tsien 1954).

The data on works of history and literature is obtained from the *Siku Quanshu* (Complete Library of the Four Treasuries) and its continuation, the *Xuxiu Siku Quanshu.*[30] *Siku Quanshu* and its continuation consolidate 808 titles pertaining to history and 1,978 titles on literature between 1500 and 1840. Based on biographies of the authors, I enumerated the number of titles by prefecture and decade.

Following the same strategy as used in analyzing the books on science, I regressed the number of works of Chinese history and literature on the Jesuit scientist presence at the prefectural level between 1581 and 1720. As reported in columns 1 to 4 of Table 9, Jesuit scientist presence had a negative effect on these historical or literacy works, though statistically insignificant.[31] The result is robust if controlling for the

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[29] The results are similar in using the negative binominal regressions to attenuate the zero inflation concern in the dependent variable (not reported).

[30] Compiled by more than 3,600 scholars supervised by the Qing court between 1773 and 1784, the *Siku Quanshu* is one of the most comprehensive book collections in Chinese history. It comprises 3,461 titles and 2.3 million pages. In 2002, the Shanghai Guji Press published the continuation to the *Siku Quanshu* by complementing the original with 1,752 more titles. These titles included those published before 1784 but censored by the *Siku Quanshu* for political reasons, and those published after 1784.

[31] The only exception is the instrumented result within the Jesuit prefectures (column 4), in which the effect of Jesuit scientist presence is significant at the 10 percent level. This implies that the Jesuits' diffusion of European sciences might slightly crowd out studies on history and literature written by Chinese literati.

other prefectural factors, restricting the sample to only the Jesuit prefectures, and using the distance to Ricci route to instrument Jesuit scientist presence.

In a panel data setting, I examine the effects of Jesuit scientist entry and expulsion (columns 5–8). Again, both have no significant impacts on production on works of history and literature by Chinese literati. This suggests that the increasing number of Chinese scientific publications after 1580 was triggered by the introduction of European sciences rather than by any unobserved correlates with book production.

[Table 9 about here]

4.5. Regional Spillover

Over time, European scientific knowledge might have diffused to areas beyond those where Jesuit scientists resided, allowing the Chinese literati who did not have the opportunity to meet the Jesuit scientists to also have access to the European sciences. Such diffusion was most likely through the translations of European scientific works, correspondence, and word of mouth in literati circles (Xiong 1994), although there are no systematic records on it. As a second-best alternative, I use a prefecture's shortest great circle distance to the nearest prefecture where there were Jesuit scientists between 1581 and 1720 as the proxy for the regional spillover of European science knowledge (hereafter, distance to Jesuit scientists). The distance is measured in kilometers, and its logarithm is taken to capture its nonlinear effect on the number of Chinese scientific works.[32]

The OLS and 2SLS results are reported in Table 10. The 2SLS estimations use the distance to Ricci route as the instrumental variable of the distance to Jesuit scientists. I control for all the prefectural observables as I did in Table 1. The results show that the distance to Jesuit scientists had no effect on Chinese scientific production before the Jesuits came to China in 1580. After then, the distance to Jesuit scientists turns to be significantly negative in predicting the number of Chinese scientific works, suggesting a regional spillover effect of the Jesuits' scientific activities. In terms of magnitude, the instrumented result shows that a 100 percent increase in the distance from Jesuit scientists' residence, which is 188 kilometers and roughly spans two prefectures, would decrease the number of Chinese scientific works by 0.784 (column 4). After the Jesuit scientists were expelled from China, the effect of the distance to Jesuit scientists turned to be insignificant; this suggests that the previous spillover of the Jesuits' knowledge did not persist after the Sino-Europe

[32] Alternatively, I use the quadratic equation of the distance, i.e., distance + distance^2, and obtain similar results (not reported).

contact was broken.[33]

[Table 10 about here]

5. Conclusion

The Jesuits introduced China to the European sciences from 1580. Both historical anecdotes and statistical evidence indicate that many Chinese literati, stimulated by the novel European sciences, deliberately learnt more about them from the Jesuits. They then devoted themselves to scientific research using these new methods to further scientific knowledge in China. Correspondingly, Chinese scientific production increased significantly in the 17th and 18th centuries.

Although the Chinese scientific movement was small in scale and less revolutionary compared to that of contemporaneous Europe, it indicates that the Chinese knowledge elites in the Ming-Qing period did not lack an interest in science nor were they opposed to learning from the West. Instead, the imperial examination system cultivated a learned group who contributed to China's scientific progress upon comprehension of frontier knowledge from Europe. It is beyond the scope of this paper to examine the reasons why China does not appear to have succeeded in developing modern science and industrialization after the 14th century. However, its findings 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 other factors. In general, the triggering effect of the Jesuits on Chinese scientific production illuminates the importance of an environment conducive to knowledge diffusion in scientific progress.

[33] The results are consistent when using negative binominal estimations to attenuate the zero inflation problem in the dependent variable (not reported).

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Figures and Tables

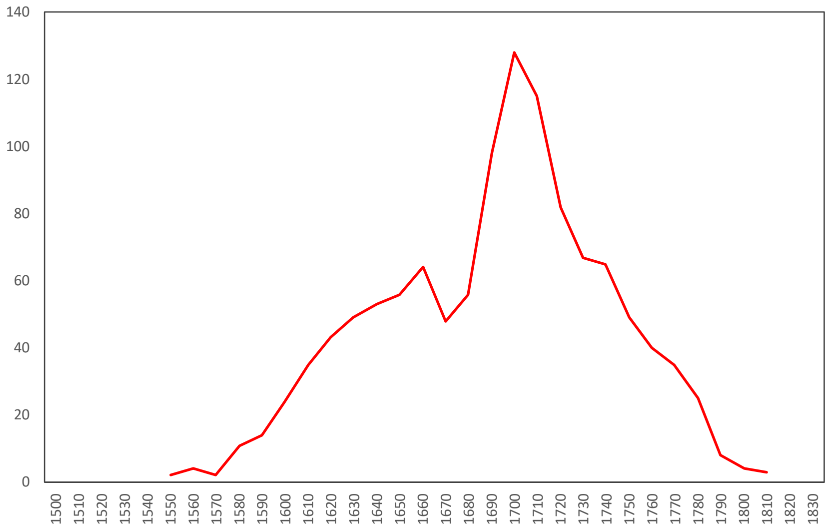


Figure 1. Number of Jesuits in China by Decade

Notes: The data is based on Dehergne (1973).

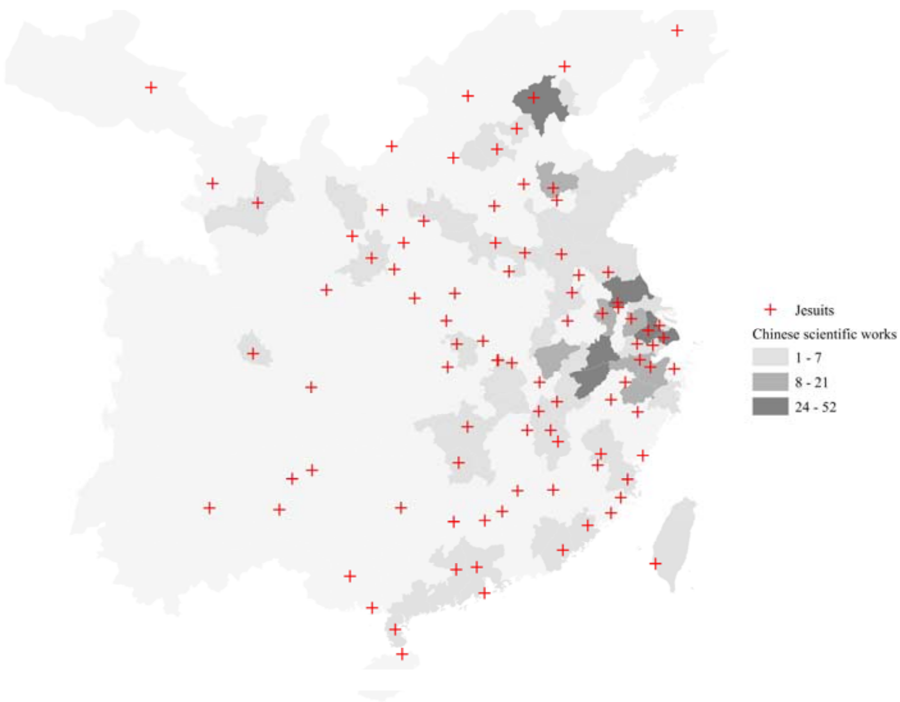


Figure 2. Distribution of Jesuits and Chinese Scientific Works in China Proper, 1581–1840

Notes: The data on Jesuits is based on Dehergne (1973). Chinese scientific works refer to the number of book titles on sciences written by Chinese. The data is obtained from *Zhongguo Kexue Jishu Dianji Tonghui* (Collection of Chinese Classic Works in Science and Technology).

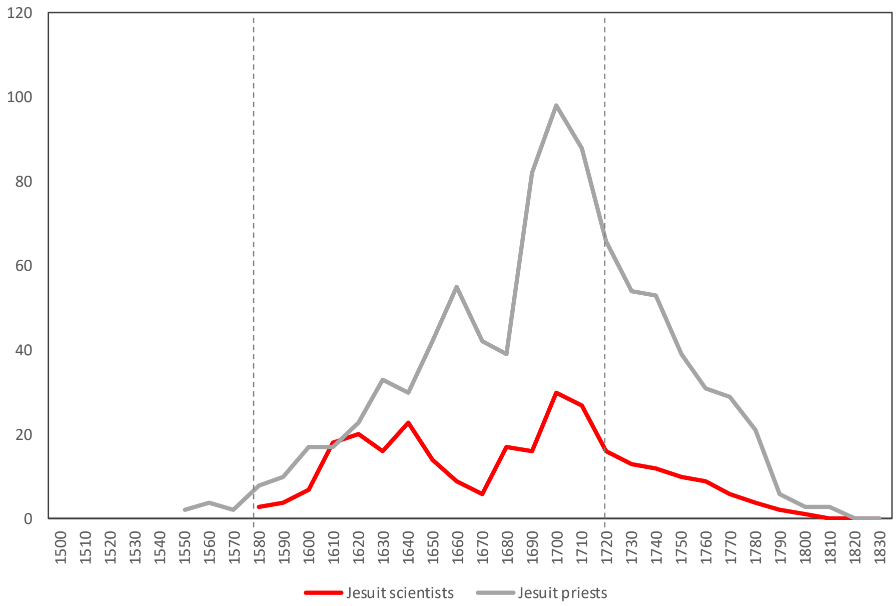


Figure 3. Numbers of Jesuit Scientists and Priests in China, by Decade

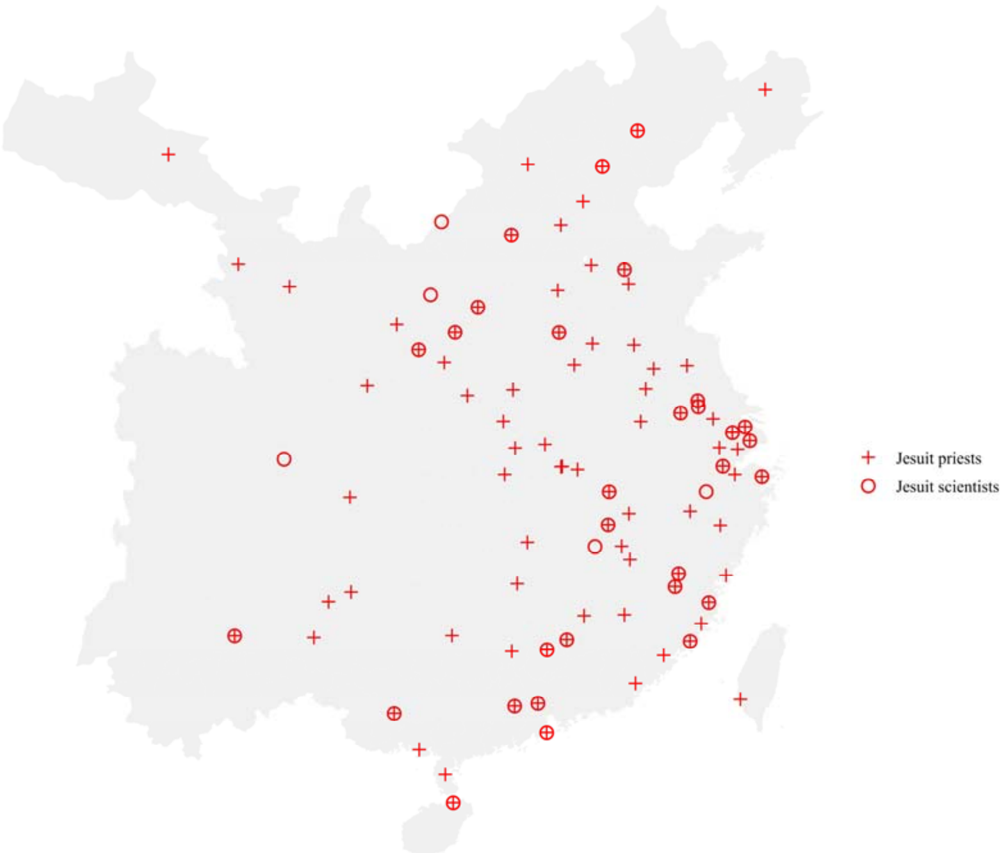
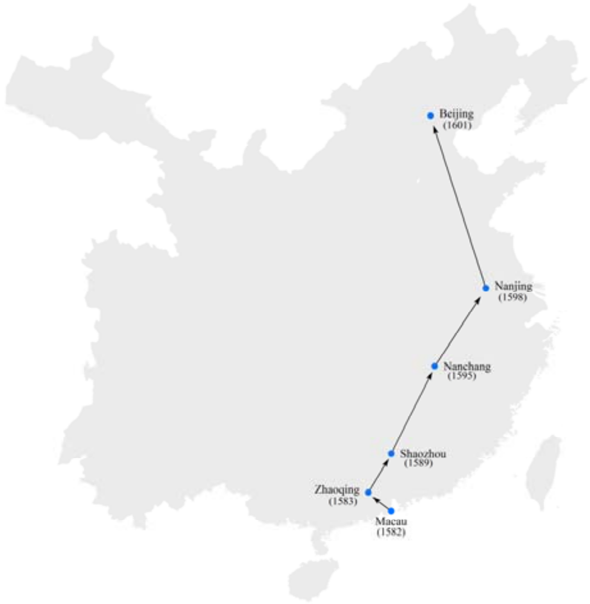
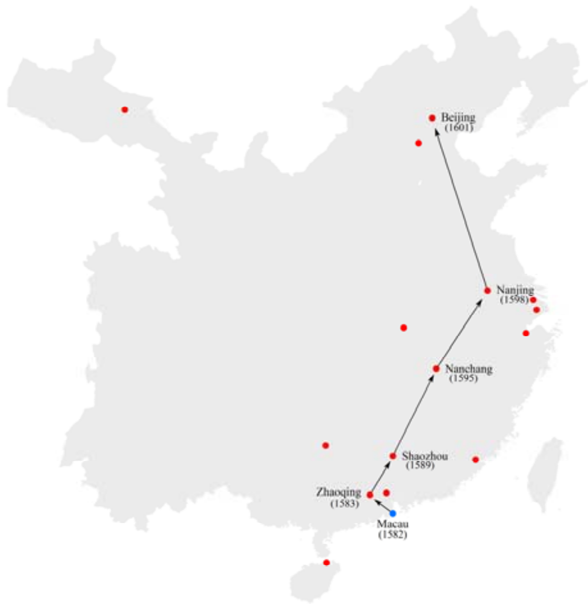


Figure 4. Distributions of Jesuit Scientists and Priests in China Proper, 1580–1820

Figure 5. Number of Chinese Scientific Works (Book Titles) by Decade



(a) Matteo Ricci's Missionary Route and Stations



(b) Presence of Jesuit 1581-1610

(c) Presence of Jesuit 1581-1680

(d) Presence of Jesuit 1581-1720

Figure 6. Matteo Ricci's Missionary Route and the Distribution of the Jesuits

Table 1. The Effect of the Presence of Jesuit Scientists on Chinese Science

	Pre-Jesuit 1501–1580		Jesuit presence 1581–1720		Jesuit expulsion 1721–1840	
	1	2	3	4	5	6
Jesuit scientist presence	0.403	0.288	2.368**	1.705**	1.549	1.248
	(0.250)	(0.239)	(0.980)	(0.849)	(1.082)	(1.051)
Log Population		0.148***		0.388**		0.173
		(0.052)		(0.179)		(0.301)
Log Literati (*jinshi*)		0.070		0.326*		0.604*
		(0.068)		(0.189)		(0.324)
Log Urbanization rate		0.014		0.072		0.086
		(0.016)		(0.061)		(0.057)
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	254	252	254	252	254	252
R-squared	0.093	0.130	0.140	0.204	0.389	0.401

Notes: All are OLS estimates at the prefectural level. Dependent variable is Chinese scientific works. Jesuit scientist presence is a dummy that equals 1 if a prefecture had Jesuit scientists between 1581 and 1720. Pre-Jesuit 1501–1580 is taken as a placebo. Jesuit expulsion 1721–1840 is the period when China's imperial authorities gradually expelled the Jesuits from China. Geographic controls include agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. In addition, Chinese scientific works 1501–1580 is controlled in column 4. Chinese scientific works 1501–1720 is controlled in column 6. Heteroskedasticity–robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 2. Jesuit Priests as the Placebo

	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840
	1	2	3	4	5	6
Jesuit priest presence	0.123	0.418	0.134	0.043	-0.085	-0.240
	(0.121)	(0.459)	(0.564)	(0.129)	(0.383)	(0.446)
Jesuit scientist presence				0.269	1.743**	1.354
				(0.256)	(0.828)	(0.998)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	252	252	252	252	252	252
R-squared	0.121	0.175	0.391	0.130	0.204	0.401

Notes: All are OLS estimates at the prefectural level. Dependent variable is Chinese scientific works. Jesuit priest presence is a dummy that equals 1 if a prefecture had Jesuit priests between 1580 and 1720. Controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Chinese scientific works 1501–1580 is controlled in columns 2 and 5. Chinese scientific works 1501–1720 is controlled in columns 3 and 6. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 3. The Effect of the Presence of Jesuit Scientists on Chinese Science: Prefectures with Jesuit Presence, 1581–1720

	Pre-Jesuit 1501–1580		Jesuit presence 1581–1720		Jesuit expulsion 1721–1840	
	1	2	3	4	5	6
Jesuit scientist presence	0.343	0.263	2.041**	1.549**	1.423	1.199
	(0.293)	(0.284)	(0.969)	(0.748)	(1.039)	(0.995)
Log Population		Yes		Yes		Yes
Log Literati (*jinshi*)		Yes		Yes		Yes
Log Urbanization rate		Yes		Yes		Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	81	80	81	80	81	80
R-squared	0.169	0.216	0.245	0.308	0.597	0.614

Notes: All are OLS estimates at the prefectural level. Prefectures without Jesuits throughout 1581–1720 are excluded. Dependent variable is Chinese scientific works. Geographic controls include agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Chinese scientific works 1501–1580 is controlled in columns 3 and 4. Chinese scientific works 1501–1720 is controlled in columns 5 and 6. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 4. Distance to Matteo Ricci's Missionary Route and the Distribution of Jesuit Scientists

	Jesuit scientist presence			Jesuit scientist number
	1	2	3	4
Log Distance to Ricci route	-0.081***	-0.080***	-0.098***	-1.394**
	(0.024)	(0.025)	(0.027)	(0.596)
Log Distance to Nanjing			0.007	0.238
			(0.053)	(0.873)
Log Distance to Beijing			0.104**	-4.676
			(0.051)	(3.029)
Controls		Yes	Yes	Yes
Observations	173	171	171	171
R-squared	0.080	0.210	0.238	0.443

Notes: All are OLS estimates at the prefectural level. The Probit estimation results are similar for columns 1–3 (not reported). Distance to Ricci route refers to a prefecture's shortest distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601. Controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, log land area, and Chinese scientific works in 1501–1580. Five provinces in western China (Gansu, Shaanxi, Sichuan, Guizhou and Yunnan) are excluded. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 5. Exclusion Restriction and the Reduced-Form Results

	Log Population 1580	Log Literati 1501–1580	Chinese science works 1501–1580	Chinese science works 1581–1720	Chinese science works 1721–1840	Chinese science works 1581–1720
	1	2	3	4	5	6
Log Distance to Ricci route	0.012	0.059	0.019	-0.455*	0.267	-0.497*
	(0.056)	(0.047)	(0.054)	(0.247)	(0.194)	(0.253)
Log Distance to Nanjing	-0.488***	-0.019	-0.131	-0.710	-0.603	-0.707
	(0.113)	(0.114)	(0.101)	(0.567)	(0.564)	(0.558)
Log Distance to Beijing	-0.142*	-0.278***	0.080	-1.512	-0.155	-1.575
	(0.074)	(0.082)	(0.094)	(1.094)	(0.522)	(1.090)
Log Distance to courier routes						0.161
						(0.142)
Log Population		Yes	Yes	Yes	Yes	Yes
Log Literati			Yes	Yes	Yes	Yes
Log Urbanization 1580			Yes	Yes	Yes	Yes
Geography controls	Yes	Yes	Yes	Yes	Yes	Yes
Chinese science works 1501–1580				Yes		Yes
Chinese science works 1581–1720					Yes	
Observations	171	171	171	171	171	171
R-squared	0.352	0.229	0.155	0.322	0.392	0.329

Notes: All are OLS estimates at the prefectural level. The negative binominal regression results are similar for columns 3–6 (not reported). Distance to Ricci route refers to a prefecture's shortest distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601. Distance to courier routes refers to a prefecture's shortest distance to the nearest courier route. Geographic controls include agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Five provinces in western China (Gansu, Shaanxi, Sichuan, Guizhou and Yunnan) are excluded. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 6. The Effect of the Presence of Jesuit Scientists on Chinese Scientific Works: Instrumented Results

	Pre-Jesuit 1501–1580		Jesuit presence 1581–1720		Jesuit expulsion 1721–1840	
	1	2	3	4	5	6
Second stage						
Jesuit scientist presence	-0.345	-0.221	5.404*	4.648**	0.294	-3.876
	(0.744)	(0.604)	(2.907)	(2.274)	(3.307)	(3.180)
R-squared	0.035	0.136	0.205	0.274	0.184	0.250
First stage						
Log Distance to Ricci route	-0.085***	-0.087***	-0.085***	-0.098***	-0.085***	-0.069**
	(0.029)	(0.028)	(0.029)	(0.027)	(0.029)	(0.028)
Partial R-squared of the IV	0.070	0.075	0.070	0.095	0.070	0.050
Controls in the two stages						
Log Population		Yes		Yes		Yes
Log Literati (*jinshi*)		Yes		Yes		Yes
Log Urbanization rate		Yes		Yes		Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	173	171	173	171	173	171

Notes: All are 2SLS estimates at the prefectural level. Dependent variable is Chinese scientific works. Jesuit scientist presence is instrumented by a prefecture's shortest distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601 (in log). Geographic controls include agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, log land area, log distance to Nanjing and log distance to Beijing. Chinese scientific works 1501–1580 is controlled in column 4. Chinese scientific works 1501–1720 is controlled in column 6. Five provinces in western China (Gansu, Shaanxi, Sichuan, Guizhou and Yunnan) are excluded. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 7. The Effect of Jesuit Entry on Chinese Science, 1501–1720

	Chinese scientific works			
	1	2	3	4
Jesuit scientist entry	0.137*	0.139*	0.129*	0.136**
	(0.081)	(0.081)	(0.074)	(0.065)
Jesuit priest entry		0.018		0.016
		(0.033)		(0.047)
Controls	Yes	Yes	Yes	Yes
Prefecture fixed-effects	Yes	Yes	Yes	Yes
Decade fixed-effects	Yes	Yes	Yes	Yes
Observations	5,544	5,544	1,760	1,760
Number of prefectures	252	252	80	80
R-squared	0.009	0.009	0.020	0.020
Sample prefectures	All	All	Jesuits	Jesuits

Notes: Dependent variable is decadal number of Chinese scientific works at the prefectural level. Jesuit scientist (priest) entry is a dummy indicating the period after the first Jesuit scientist (priest) arrived in a prefecture. All are OLS estimates. The negative binominal regression results are similar (not reported). Controls include log population and log literati (number of *jinshi* in recent 30 years per 10,000 persons). Prefectures without Jesuits presence throughout 1581–1720 are excluded in columns 3 and 4. Standard errors clustered at the prefectural level are reported in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 8. The Effect of Jesuit Expulsion on Chinese Science, 1701–1840

	Chinese scientific works			
	1	2	3	4
Jesuit scientist expulsion	-0.354*	-0.352*	-0.388**	-0.408**
	(0.180)	(0.183)	(0.190)	(0.197)
Jesuit priest expulsion		0.011		-0.050
		(0.073)		(0.096)
Controls	Yes	Yes	Yes	Yes
Prefecture fixed-effects	Yes	Yes	Yes	Yes
Decade fixed-effects	Yes	Yes	Yes	Yes
Observations	3,528	3,528	1,120	1,120
Number of prefectures	252	252	80	80
R-squared	0.009	0.009	0.021	0.021
Sample prefectures	All	All	Jesuits	Jesuits

Notes: Dependent variable is decadal number of Chinese scientific works at the prefectural level. Jesuit scientist (priest) expulsion is a dummy indicating the period after all the Jesuit scientists (priests) had been expelled from a prefecture. All are OLS estimates. The negative binominal regression results are similar (not reported). Controls include log population and log literati (number of *jinshi* in recent 30 years per 10,000 persons). Prefectures without Jesuits presence throughout 1581–1720 are excluded in columns 3 and 4. Standard errors clustered at the prefectural level are reported in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 9. The Effect of Jesuit Scientists on Works of History and Literature by Chinese Literati

	Cross-prefectural regressions 1580–1720				Panel data regressions 1501–1720		Panel data regressions 1701–1840	
	OLS	2SLS	OLS	2SLS	OLS	OLS	OLS	OLS
	1	2	3	4	5	6	7	8
Jesuit scientist presence	-2.735	-14.022	-4.806	-16.298*				
	(3.841)	(9.170)	(5.279)	(9.440)				
Jesuit scientist entry					0.046	0.075		
					(0.359)	(0.367)		
Jesuit scientist expulsion							-0.122	-0.134
							(0.242)	(0.282)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prefecture fixed effects					Yes	Yes	Yes	Yes
Decade fixed effects					Yes	Yes	Yes	Yes
Observations	252	250	80	80	5,544	1,760	3,024	960
Number of prefectures	252	250	80	80	252	80	252	80
R-squared	0.730	0.745	0.757	0.794	0.012	0.022	0.007	0.019
Sample prefectures	All	All	Jesuits	Jesuits	All	Jesuits	All	Jesuits

Notes: Dependent variable is the number of Chinese books (titles) on history and literature. Columns 2 and 4 use the log distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601 as the instrumental variable of the Jesuit scientist presence. In columns 1–4, controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, log land area, and number of Chinese historical works published in 1501–1580. Heteroskedasticity-robust standard errors are reported in parentheses. In columns 5–8, controls are log population and log literati (*jinshi*) at the prefecture-decade level. Standard errors clustered at the prefectural level are reported in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table 10. Regional Spillover Effect of the Jesuit Scientists

	Pre-Jesuit 1501–1580		Jesuit presence 1581–1720		Jesuit expulsion 1721–1840	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	1	2	3	4	5	6
Log Distance to Jesuit scientist	-0.056	0.050	-0.312**	-0.784*	-0.226	0.791
	(0.041)	(0.113)	(0.151)	(0.463)	(0.189)	(0.549)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	250	250	250	250	250	250
R-squared	0.131	0.036	0.201	0.083	0.400	0.323

Notes: All are cross-prefectural regression results. Dependent variable is the number of Chinese scientific works. Regional spillover is proxied by a prefecture's geographic distance to the nearest prefecture where there were Jesuit scientists in 1581–1720 (in log). Columns 2, 4, and 6 use the log distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601 as the instrumental variable of the log distance to Jesuit scientist. All regressions have controlled for log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Chinese scientific works 1501–1580 is controlled in columns 3 and 4. Chinese scientific works 1501–1720 is controlled in columns 5 and 6. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Online Appendices

Appendix 1. Figures

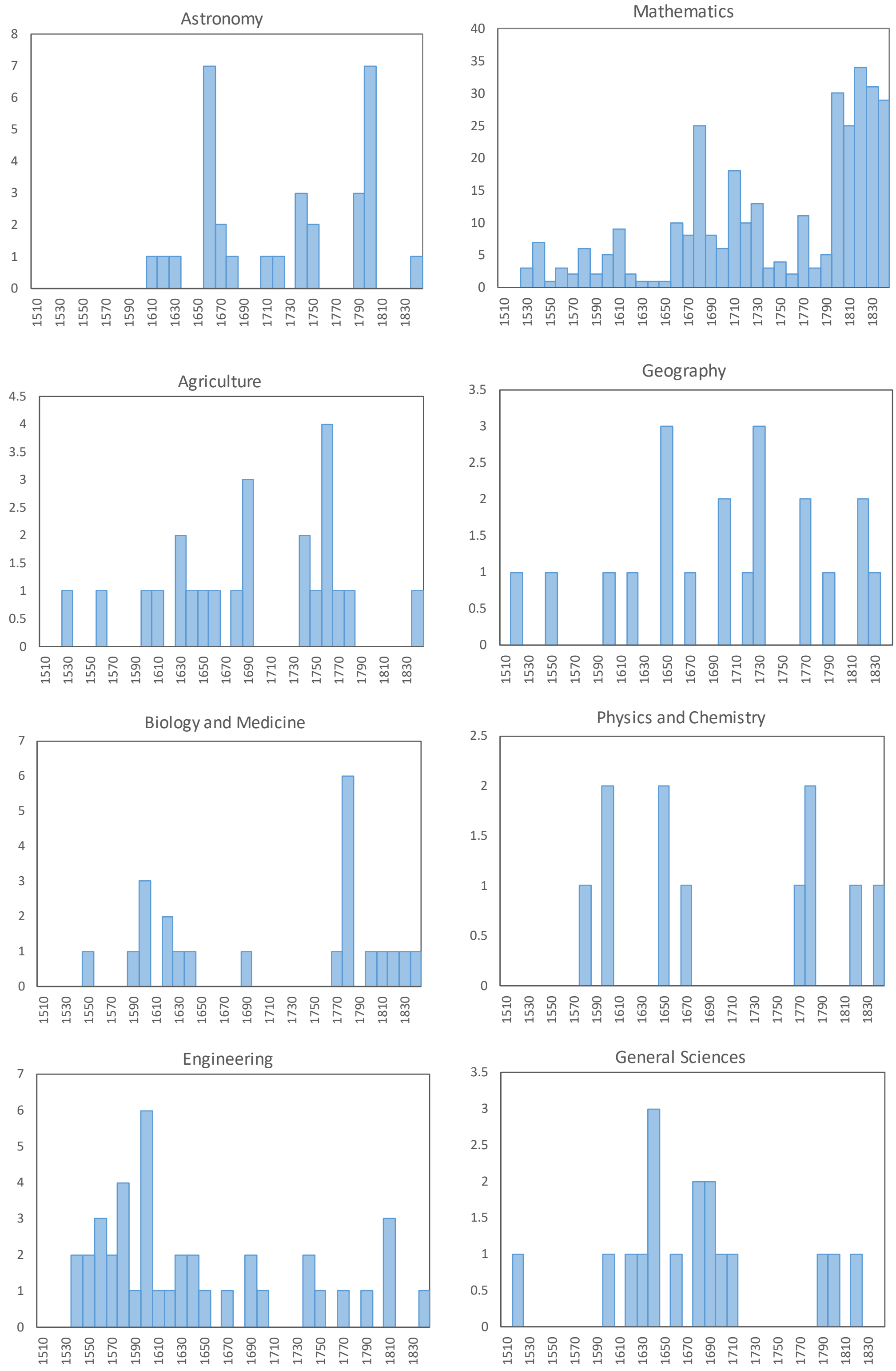


Figure A1. Number of Chinese Scientific Works, by Subject

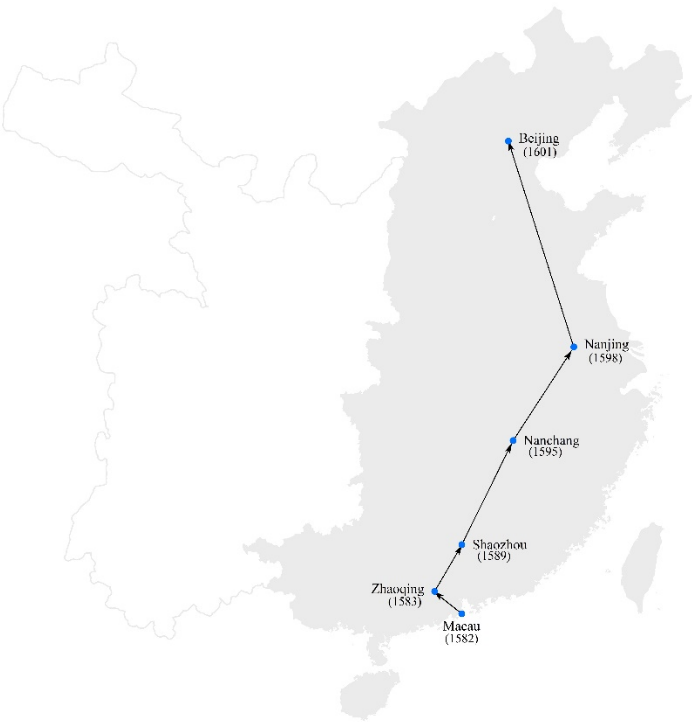


Figure A2. Sample Region Excluding Western Provinces (Gansu, Shaanxi, Sichuan, Guizhou, and Yunnan)

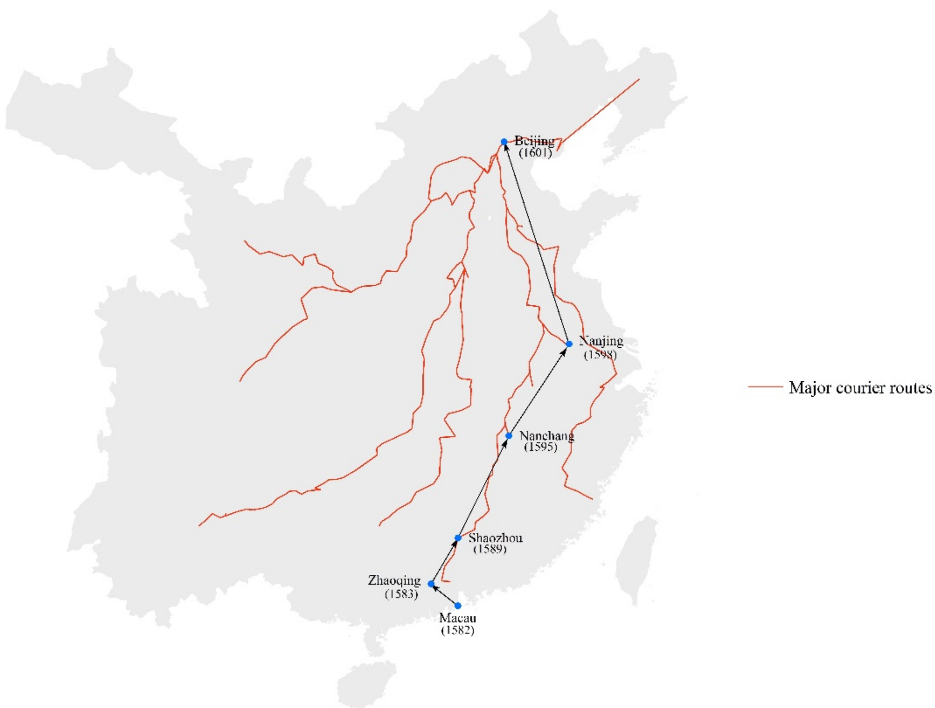


Figure A3. The Courier Routes and Matteo Ricci's Missionary Route in Ming China

Appendix 2. Tables

Table A1. The Jesuit Scientists in China

Name	Chinese Name	Nationality	Birth-Death Year	Scientific Fields
Giulio Alenio	艾儒略	Italy	1582–1649	Astronomy, Mathematics, Geography
José Bernardo de Almeida	索德超	Portugal	1728–1805	Astronomy
Michel Benoist	蒋友仁	France	1715–1774	Architecture; Astronomy; Geography
Joachim Bouvet	白晋	France	1656–1730	Astronomy; Mathematics; Geography; Chemistry
Franciscus Brancati	潘国光	Italy	1607–1671	Astronomy
Jacques Brocard	陆伯嘉	France	1661–1718	Mechanics
Lodovico Buglio	利类思	Italy	1606–1682	Biology
João Francisco Cardoso	麦大成	Portugal	1676–1723	Geography
Giuseppe Castiglione	郎世宁	Italy	1688–1766	Architecture; Astronomy
Caspar Castner	庞嘉宾	Germany	1665–1708	Astronomy
Giovanni Giuseppe da Costa	罗怀忠	Italy	1679–1747	Medical Science
Pierre Vincent de Tartre	汤尚贤	France	1669–1724	Geography
Sabatino (Sabbathin) de Ursis	熊三拔	Italy	1575–1620	Astronomy; Hydraulics
Emmanuel Diaz Júnior	阳玛诺	Portugal	1574–1659	Astronomy
José d'Espinha	高慎思	Portugal	1722–1788	Astronomy; Geography
Jean–François Foucquet	傅圣泽	France	1665–1741	Mathematics
Pierre Frapperie	樊继训	France	1664–1703	Medical Science
Ehrenbert Xaver Fridelli	费隐	Austria	1673–1743	Geography
Jean de Fontaney	洪若翰	France	1643–1710	Natural Science
Francois Furtado	傅汎际	Portugal	1587–1653	Astronomy
Antoine Gaubil	宋君荣	France	1689–1759	Astronomy
Jean-Francois Gerbillon	张诚	France	1654–1707	Astronomy; Mathematics; Geography
Anton Gogeisl	鲍友管	Germany	1701–1771	Astronomy
Philippus Maria Grimaldi	闵明我	Italy	1639–1712	Astronomy
Augustin von Hallerstein	刘松龄	Austria	1703–1774	Astronomy; Mathematics; Geography
Pierre Jartoux	杜德美	France	1669?–1721?	Astronomy; Mathematics
Ignaz Kögler	戴进贤	Germany	1680–1746	Astronomy; Mathematics
Nicolas Longobardi	龙华民	Italy	1559–1654	Astronomy; Seismology
Gabriel de Magalhães	安文思	Portugal	1609–1677	Astronomy
Joseph de Mailla	冯秉正	France	1669–1748	Geography
Martin Martini	卫匡国	Italy	1614–1661	Geography
Manuel de Mattos	罗启明	Portugal	1725–1764	Medical Science
Fernando Bonaventure Moggi	利博明	Italy	1684–1761	Architecture
Didace de Pantoja	庞迪我	Spain	1571–1618	Astronomy
Dominique Parrenin	巴多明	France	1665–1741	Anatomy; Medical Science; Geography
Andreas Pereira	徐懋德	Portugal	1689–1743	Astronomy
Thomas Pereyra	徐日升	Portugal	1645–1708	Astronomy
Jean-Baptiste Regis	雷孝思	France	1664–1738	Geography
Giacomo Rho	罗雅谷	Italy	1592–1638	Astronomy
Matteo Ricci	利玛窦	Italy	1552–1610	Astronomy; Mathematics; Geography
Felix da Rocha	傅作霖	Portugal	1713–1781	Astronomy; Geography
Bernard Rhodes	罗德先	France	1646–1715	Medicine
André Rodrigues	安国宁	Portugal	1729–1796	Astronomy; Mathematics
Étienne Rousset	佟泰	France	1689–1758	Astronomy
Andrius Rudamina	卢安德	Lithuania	1596–1631	Astronomy
Francesco Sambiaso	毕方济	Italy	1582–1649	Astronomy; Mining Science; Geography
Johann Adam Schall von Bell	汤若望	Germany	1591–1666	Astronomy; Mathematics; Physics; Chemistry
Johann Terrenz Schreck	邓玉函	Germany	1576–1630	Astronomy; Medicine; Physics
Jean Nicolas Smogolenski	穆尼阁	Poland	1611–1656	Astronomy; Mathematics
Franz Stadlin	林济各	Switzerland	1658–1740	Mechanics
Joseph Suarez	苏霖	Portugal	1656–1736	Astronomy; Mechanics
Kilian Stumpf	纪理安	Germany	1655–1720	Astronomy
Antoine Thomas	安多	Belgium	1644–1709	Astronomy; Mathematics
Nicolas Trigault	金尼阁	France	1577–1628	Natural Science
Alfonso Vagnoni	高一志	Italy	1566–1640	Astronomy
Ferdinand Verbiest	南怀仁	Belgium	1623–1688	Astronomy; Mechanics

Table A2. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Chinese science					
Chinese scientific works (1501–1580)	254	0.17	0.82	0	9
Chinese scientific works (1581–1720)	254	0.73	3.03	0	29
Chinese scientific works (1721–1840)	254	0.99	3.81	0	30
Chinese scientific works (decadal, 1501-1720)	5654	0.04	0.40	0	18
Chinese scientific works (decadal, 1701-1840)	3598	0.08	0.68	0	17
Chinese history/literature works (1501–1580)	254	4.15	13.49	0	161
Chinese history/literature works (1581–1720)	254	8.12	23.48	0	224
Chinese history/literature works (1721–1840)	254	4.16	13.52	0	107
Chinese history/literature works (decadal, 1501-1720)	5654	0.58	2.22	0	31
Chinese history/literature works (decadal, 1701-1840)	3084	0.49	2.22	0	34
Jesuits					
Jesuit scientist presence (1581–1720)	254	0.13	0.34	0	1
Jesuit scientist number (1581–1720)	254	0.83	5.34	0	80
Jesuit scientist entry (decadal, 1501-1720)	5654	0.05	0.23	0	1
Jesuit scientist expulsion (decadal, 1701-1840)	3598	0.12	0.33	0	1
Jesuit scientist number (decadal cumulative, 1501-1840)	8636	0.52	5.40	0	148
Jesuit priest presence (1581–1720)	254	0.30	0.46	0	1
Jesuit priest number (1581–1720)	254	2.30	7.61	0	82
Jesuit priest entry (decadal, 1501-1720)	5654	0.05	0.22	0	1
Jesuit priest expulsion (decadal, 1701-1840)	3598	0.16	0.37	0	1
Jesuit priest number (decadal cumulative, 1501-1840)	8636	0.40	2.39	0	59
Distance to Jesuit scientists	252	187.71	167.46	0	1235.79
Controls					
Population (1501–1580)	252	660.54	685.11	14.39	3601.47
Population (1581–1720)	252	736.11	692.66	6.85	3360.70
Population (1721–1840)	252	1329.70	1119.90	50.61	5827.33
Population (decadal)	8568	903.57	906.45	6.16	7322
Literati (*jinshi*/population) (1501–1580)	252	3.79	4.69	0	30.22
Literati (*jinshi*/population) (1581–1720)	252	12.50	32.93	0	308.23
Literati (*jinshi*/population) (1721–1840)	252	2.94	2.93	0	19.42
Literati (*jinshi 30-year*/population)	8568	1.24	2.82	0	109.35
Urbanization rate	254	5.60	7.48	0	52.85
Agricultural suitability	254	16.74	5.89	0.001	31.22
Distance to coast	254	491.87	366	0.17	1924.74
Terrain ruggedness	254	219.93	168.45	4.42	890.68
Distance to river	254	288.44	235.93	0.14	1524.15
Land area	254	16894.77	20195.03	2326.10	198269
Distance to Beijing	175	335.87	176.20	0	766.44
Distance to Nanjing	175	236.84	120.26	0	553.60
Distance to courier routes	175	84.08	110.41	0	679.89
Instrument					
Distance to Ricci route	173	259.93	175.39	0	688.47

Table A3. Determinants of the Distributions of Jesuit Scientists and Priests, 1580–1720

	Jesuit scientist presence	Jesuit priest presence	Jesuit scientist presence
	1	2	3
Log Population	0.044**	0.072***	0.070
	(0.019)	(0.023)	(0.063)
Log Literati (*jinshi*)	0.063***	0.076***	0.114*
	(0.020)	(0.022)	(0.062)
Log Urbanization rate	0.017	0.035**	0.008
	(0.011)	(0.014)	(0.036)
Log Distance to coast	-0.048*	-0.112***	-0.015
	(0.025)	(0.027)	(0.037)
Log Distance to river	0.024	-0.004	0.096*
	(0.018)	(0.023)	(0.057)
Agricultural suitability	-0.003	-0.007	0.000
	(0.005)	(0.006)	(0.012)
Log Terrain ruggedness	0.017	0.032	-0.027
	(0.027)	(0.033)	(0.072)
Log Land area	-0.003	0.058	-0.044
	(0.039)	(0.045)	(0.107)
Chinese scientific works 1501–1580	0.045	0.026	0.036
	(0.035)	(0.025)	(0.046)
Observations	252	252	80
R-squared	0.146	0.259	0.113
Sample prefectures	All	All	Jesuits

Notes: All are OLS results at the prefectural level. The logit regression results are similar and not reported. Column 3 restricts the sample to the prefectures with Jesuit presence between 1581 and 1720. Heteroskedasticity-robust standard errors are reported in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table A4. The Effect of the Number of Jesuits on Chinese Science

	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840
	1	2	3	4	5	6
Jesuit scientist number	0.001	0.347***	0.120	0.006	0.344***	0.071
	(0.009)	(0.026)	(0.082)	(0.009)	(0.027)	(0.077)
Jesuit priest number	0.011	-0.016	0.032	0.003	-0.018	0.028
	(0.014)	(0.052)	(0.041)	(0.015)	(0.059)	(0.046)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	252	252	252	80	80	80
R-squared	0.126	0.495	0.417	0.210	0.720	0.616
Sample prefectures	All	All	All	Jesuits	Jesuits	Jesuits

Notes: All are OLS estimates at the prefectural level. Dependent variable is the number of Chinese scientific works at the prefectural level. Jesuit scientist (priest) number is the total number-decades of Jesuit scientists (priests) in a prefecture between 1581 and 1720. Controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Chinese scientific works 1501–1580 is controlled in columns 2 and 5. Chinese scientific works 1501–1720 is controlled in columns 3 and 6. Columns 4–6 restrict the analysis to the prefectures with Jesuit presence between 1581 and 1720. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table A5. Effect of Jesuit Presence on Chinese Science: Negative Binominal Estimations

	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840
	1	2	3
Panel A. Full sample			
Jesuit scientist presence	-0.155	0.755*	-0.377
	(0.475)	(0.445)	(0.513)
Panel B. Full sample: Horse race			
Jesuit scientist presence	-0.005	1.140**	-0.153
	(0.550)	(0.481)	(0.523)
Jesuit priest presence	-0.414	-0.843	-0.468
	(0.540)	(0.601)	(0.451)
Panel C. Jesuit prefectures only			
Jesuit scientist presence	0.425	0.883**	0.660
	(0.530)	(0.390)	(0.432)
Controls in each panel	Yes	Yes	Yes
Observations	252	252	252

Notes: This table reports the results using the negative binominal regressions to address the zero inflation in the dependent variables. Dependent variable is the number of Chinese scientific works at the prefectural level. Jesuit scientist (priest) number is the total number-decades of Jesuit scientists (priests) in a prefecture between 1581 and 1720. Controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, and log land area. Chinese scientific works 1501–1580 is controlled in column 2. Chinese scientific works 1501–1720 is controlled in column 3. Panel C restricts the analysis to the prefectures with Jesuit presence between 1581 and 1720. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Table A6. The Effect of Jesuit Scientist Number on Chinese Scientific Works: Instrumented Results with Different Estimation and Measures

	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840	Pre-Jesuit 1501–1580	Jesuit presence 1581–1720	Jesuit expulsion 1721–1840
	IV-Poisson	IV-Poisson	IV-Poisson	2SLS	2SLS	2SLS
	1	2	3	4	5	6
Jesuit scientist presence	-0.103	1.631**	-1.053			
	(1.596)	(0.790)	(1.235)			
Jesuit scientist number				-0.015	0.326***	-0.258
				(0.041)	(0.096)	(0.234)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared				0.136	0.518	0.244
Observations	171	171	171	171	171	171

Notes: Dependent variable is Chinese scientific works. Five provinces in western China (Gansu, Shaanxi, Sichuan, Guizhou and Yunnan) are excluded. Columns 1–3 use the IV-Poisson two-stage GMM estimations to address the zero inflation in the dependent variables. Columns 4–6 are 2SLS results using the total number-decades of all the Jesuit scientists in a prefecture between 1581 and 1720 as the alternative measure. The instrumental variable is a prefecture's shortest distance to the Jesuit pioneer Matteo Ricci's missionary route in China in 1582–1601. Controls include log population, log literati (*jinshi*), log urbanization rate, agricultural suitability, log distance to coast, log distance to river, log terrain ruggedness, log land area, and log distance to Beijing and log distance to Nanjing. Chinese scientific works 1501–1580 is controlled in columns 2 and 5. Chinese scientific works 1501–1720 is controlled in columns 3 and 6. Heteroskedasticity-robust standard errors in parentheses. *, ** and *** indicate the level of significance at 10%, 5% and 1%, respectively.

Appendix 3. The Jesuits' Entry to China

This table briefly introduces the means of the Jesuits' entry into the 20 prefectures of China for which Jesuit presence is recorded, for the purpose of demonstrating the randomness of the time of entry. The locations of these 20 prefectures are shown in Figure A4.

No.	Prefecture	Year of entrance	Means of entrance
1	Macau	1562	After Macau was occupied by the Portuguese in 1557, the Jesuits Baltasar Gago, Andre Pinto, and Giovanni De Monte entered Macau to establish the first Jesuit base in China in 1562.
2	Zhaoqing	1582	By following Portuguese merchants, Michele Ruggieri arrived in Guangzhou in 1580, and established a friendship with the provincial governor of Guangdong. In 1582, Ruggieri was allowed to reside in Zhaoqing.
3	Shaozhou	1589	The new prefect of Zhaoqing was hostile to the Jesuits. Matteo Ricci asked the provincial governor of Guangdong for another residence. The governor recommended Shaozhou.
4	Nanchang	1595	Matteo Ricci's first attempt to enter Nanjing in 1595 failed. His friend, She Li, a minister at Beijing, recommended that Ricci reside in Nanchang in Jiangxi Province.
5	Nanjing	1597	After having established himself as a renowned scholar, Ricci was supported by the local officials to reside in Nanjing, the auxiliary capital of the Ming dynasty, in 1597.
6	Beijing	1601	Because of his friendship with a prestigious eunuch from the imperial palace, Matteo Ricci followed this eunuch north, intending to enter Beijing. However, Ricci was arrested at Tianjin because his visit was illegal (i.e., not on the list of Ming tributary missions). But the Wanli emperor received Ricci's tribute of mechanical clocks and oil paintings, and then issued an imperial order allowing him to enter Beijing.
7	Songjiang	1608	Chinese literati Xu Guangqi had to return to his hometown Songjiang (Shanghai) in 1608 to mourn his deceased father for three years according to Chinese custom. As Xu's good friend, Lazzaro Cattaneo accompanied Xu to Songjiang.
8	Hangzhou	1612	Lazzaro Cattaneo was invited by his friends, the officials Li Zhizao and Yang Tingyun, to preach in their hometown of Hangzhou in Zhejiang Province.
9	Jiangzhou	1620	With the help of a Chinese Christian, Giulio Aleni entered Jiangzhou in Shanxi Province.
10	Suzhou	1622	Francesco Sambiasi was invited by the official Sun Yuanhua to his hometown of Jiading in Jiangsu Province.
11	Kaifeng	1623	Recommended by his friend, the official Wang Zheng, Giulio Aleni entered Kaifeng in Henan Province.
12	Fuzhou	1627	Recommended by his friend Ye Xianggao (a minister), Giulio Aleni entered Ye's hometown of Fuzhou in Fujian Province.
13	Taiwan	1636–1638	Inacio Lobo entered Taiwan when the Ming authorities were confronted by social unrest.
14	Wuchang	1638	António de Gouvea entered Wuchang in Hubei Province with the help of an official at Beijing who was his friend.
15	Jinan	1640	Requested by the Society of Jesus to open a new church along the Grand Canal (the main transportation route linking the imperial capital Beijing and the lower Yangtze), Nicholas Longobardi inspected the Grand Canal cities in 1637 and 1638, and finally chose Ji'nan in Shandong Province.
16	Chengdu	1640	Lodovico Buglio settled in Chengdu in Sichuan Province with the help of his local literati friends.
17	Yanping	1650s	Simão da Cunha expanded the missions to Yanping (and also Jiangning, Shaowu and Dingzhou) in Fujian Province along the rivers connected to the missionary bases of Fuzhou.
18	Ganzhou	1658	After the church at Nanchang was destroyed, Jacques Le Faure requested a residential permit in another city in Jiangxi Province. He settled in Ganzhou with the help of a military officer.
19	Jianchang	1661	Prospero Intorcetta entered Jianchang in Jiangxi Province with the help of another Jesuit, Ignatius da Costa.
20	Ningbo	1687	As the King's Mathematicians and with the permission of the Qing authorities, Jean de Fontaney, Joachim Bouvet, Jean-François Gerbillon, Louis Le Comte, and Claude de Visdelou landed at Ningbo in Zhejiang Province before going to Beijing.

Sources: Ricci and Trigault (1983 [1615]); Brockey (2007), Chapters 1–5.

Figure A4. The Entry of the Jesuits into Chinese Prefectures

Notes: The numbers correspond to those in the table above.