

Online Appendices

The telegraph and modern banking development,
1881—1936

August 2020

Appendix A. Figures and tables

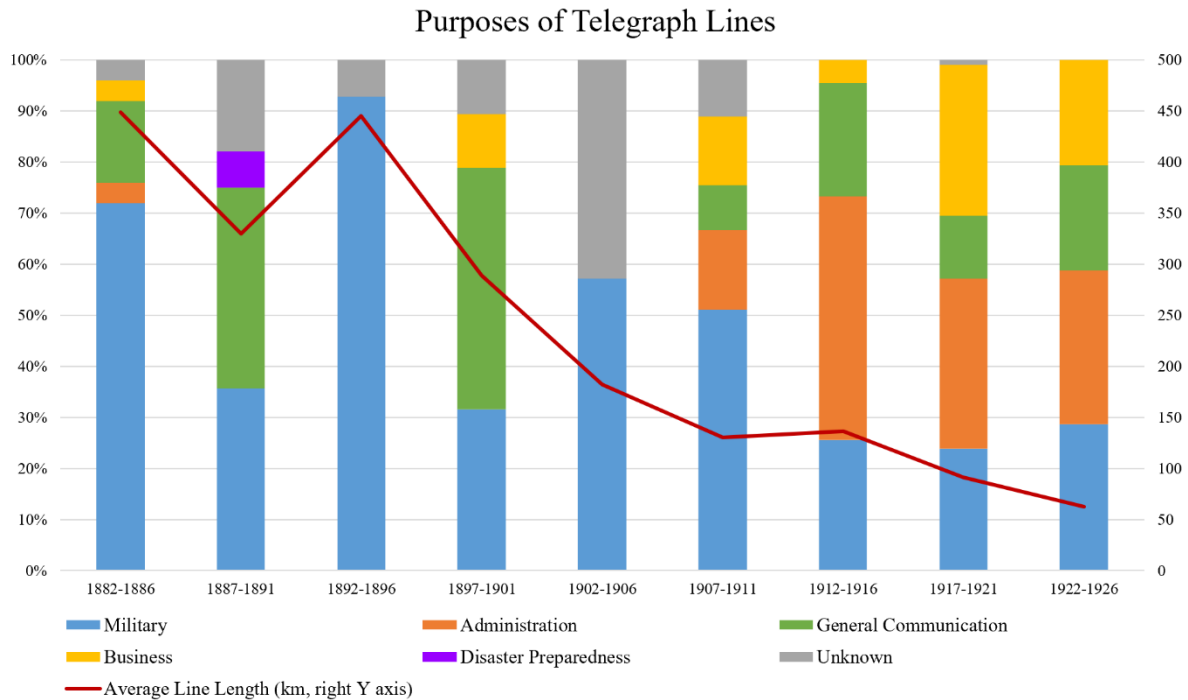


Fig. A.1. The purposes of telegraph lines. We classify the purposes for the construction of the 396 telegraph lines built between 1881 and 1925 into six categories: military, administration, general communication, business, disaster preparedness, and unknown. Line construction purposes were declared in memorials to the throne during the late Qing (Xia, 2012) and were recorded in *Jiaotongshi: Dianzhengbian* (History of Transportation: Telecommunications) (Jiaotongbu, 1931). Long-distance lines were mainly constructed during the first two decades, while short-distance lines (e.g., trunk line extensions) were added in the following years. In the early years, telegraph trunks were built mainly for military purposes while during the Republic of China (post-1912), more telegraph line extensions were added for administration and business purposes.

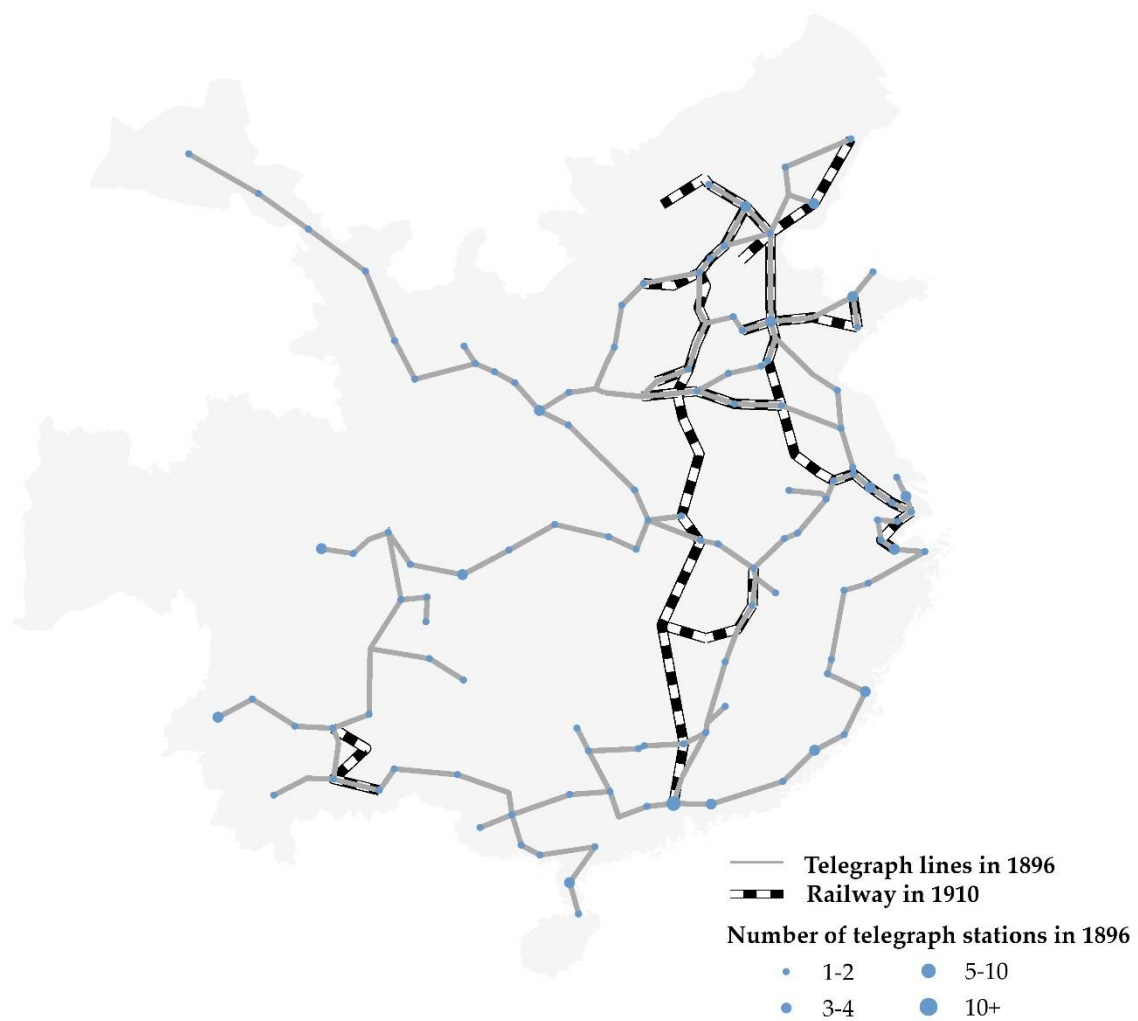


Fig. A.2. Railway network in Qing China. This figure displays the railway network in 1910 together with the telegraph network in 1896. The railway is based on Sun (2003).

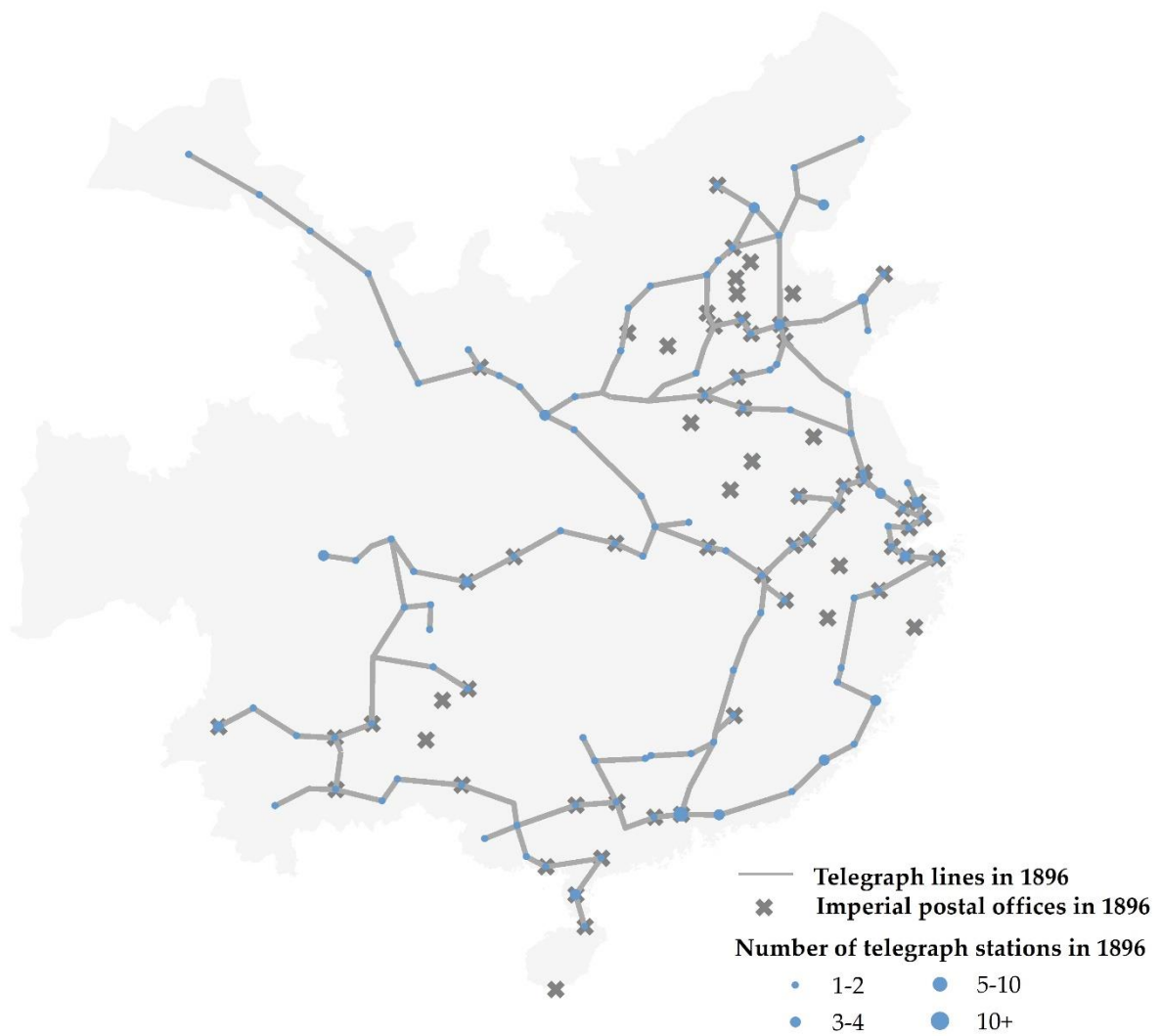


Fig. A.3. Postal offices in Qing China. This figure displays the distribution of the imperial postal offices in 1896 and that of the telegraph network in the same year. The data of the postal offices are obtained from the county gazetteers (see Appendix D2).

Table A.1

The effect of the distance to HMTN on the telegraph and banks.

Distance to HMTN is defined as the log of the great circle distance (in kilometers) from a prefecture to the hypothetical military telegraph trunk lines in 1896. Controls include population in 1880 (log), treaty ports in 1886, distance to coast (log) and land size (log). The 21 military centers (telegraph nodes) are excluded. Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Telegraph in 1896</i>	<i>Number of banks in 1911</i>		<i>Number of banks in 1936</i>		<i>Average growth of banks, 1897–1936</i>	
	1	2	3	4	5	6	7
<i>Distance to HMTN</i>	-0.147*** (0.030)	-0.058** (0.027)	-0.034 (0.030)	-0.832*** (0.265)	-0.408 (0.273)	-0.021*** (0.007)	-0.010 (0.007)
<i>Telegraph in 1896</i>			0.161* (0.085)		2.895*** (0.991)		0.072*** (0.025)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	266	266	266	266	266	266	266
R^2	0.288	0.251	0.269	0.279	0.330	0.279	0.330

Table A.2

The effect of the telegraph on banks by the distance to HMTN.

This table examines whether the effect of the telegraph on banks is greater in areas close to the HMTN relative to that of the whole sample. We arbitrarily restrict the sample regions to within 50 km or 100 km from the HMTN. The results using alternative cut-offs of distance are similar and hence are not reported. For robustness, we report both the prefectural- and county-level estimates. The 21 military centers are excluded. We use the suest test to compare the effects of the telegraph between the restricted samples (Panel A or B) and the whole sample (Panel C). All prefectural regressions have controlled for population in 1880 (log), treaty ports in 1897, distance to coast (log) and land size (log). The county regressions have controlled for distance to coast (log), land size (log) and prefectural fixed-effects. Heteroskedasticity-robust standard errors are in parentheses for prefectural level estimates. Standard errors are clustered at the prefecture-level for county-level estimates. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Number of banks in 1911</i>		<i>Number of banks in 1936</i>		<i>Average growth of banks, 1897–1936</i>	
	Prefectural level	County level	Prefectural level	County level	Prefectural level	County level
	1	2	3	4	5	6
<i>Panel A. Distance to HMTN < 50 km</i>						
<i>Telegraph in 1896</i>	0.261** (0.109)	0.378*** (0.085)	3.863*** (1.280)	3.631*** (0.651)	0.097*** (0.032)	0.091*** (0.016)
Observations	131	618	131	618	131	618
suest prob>chi ²	0.154	0.064	0.295	0.172	0.295	0.172
<i>Panel B. Distance to HMTN < 100 km</i>						
<i>Telegraph in 1896</i>	0.227** (0.088)	0.332*** (0.069)	3.388*** (1.066)	3.246*** (0.546)	0.085*** (0.027)	0.081*** (0.014)
Observations	194	978	194	978	194	978
suest prob>chi ²	0.201	0.069	0.531	0.240	0.531	0.240
<i>Panel C. Whole sample</i>						
<i>Telegraph in 1896</i>	0.184** (0.079)	0.305*** (0.061)	3.166*** (0.942)	3.007*** (0.498)	0.079*** (0.024)	0.075*** (0.012)
Observations	266	1,501	266	1,501	266	1,501

Table A.3

The effect of the telegraph on modern Chinese banks: alternative measures.

This table uses the density measurements of the banks and telegraph, i.e., the number of banks and the number of telegraph stations are both normalized by prefectural land area (in 1,000 km²) and the logarithm is taken. The 21 military centers are excluded. Telegraph density in 1896 is instrumented by the log distance to HMTN. Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Number of banks in 1911</i>		<i>Number of banks in 1936</i>		<i>Average growth of banks, 1897–1936</i>	
	1	2	3	4	5	6
<i>Panel A. Second stage estimates</i>						
<i>Telegraph in 1896</i>	0.409** (0.192)	0.406* (0.235)	5.569*** (1.152)	4.842*** (1.783)	0.139*** (0.029)	0.121*** (0.045)
Controls		Yes		Yes		Yes
Observations	266	266	266	266	266	266
<i>Panel B. First stage for telegraph in 1896</i>						
<i>Distance to HMTN</i>	-0.014*** (0.003)	-0.010*** (0.003)	-0.014*** (0.003)	-0.010*** (0.003)	-0.014*** (0.003)	-0.010*** (0.003)
K. P. F-statistic	22.781	10.725	22.781	10.725	22.781	10.725
<i>R</i> ²	0.061	0.185	0.061	0.185	0.061	0.185
<i>Panel C. OLS estimates</i>						
<i>Telegraph in 1896</i>	0.238** (0.108)	0.138* (0.075)	2.383*** (0.395)	1.529*** (0.369)	0.060*** (0.010)	0.038*** (0.009)
<i>R</i> ²	0.085	0.246	0.240	0.394	0.240	0.394

Table A.4

The effect of the telegraph on modern Chinese banks: alternative estimations.

This table reports the Tobit and Poisson estimates to address the zero-inflation concern in the number of banks. The 21 military centers are excluded. Telegraph in 1896 is instrumented by the log distance to HMTN in the IV-Tobit and IV-Poisson estimations. Controls include population size in 1880 (log), treaty ports in 1896, distance to coast (log) and land size (log). Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Number of banks in 1911</i>				<i>Number of banks in 1936</i>			
	Tobit	IV-Tobit	Poisson	IV-Poisson	Tobit	IV-Tobit	Poisson	IV-Poisson
	1	2	3	4	5	6	7	8
<i>Telegraph in 1896</i>	0.860*** (0.276)	2.250** (1.096)	0.474*** (0.159)	1.403 (0.843)	3.627*** (1.047)	9.949*** (2.874)	0.406*** (0.096)	1.467*** (0.503)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	266	266	266	266	266	266	266	266
Marginal effects			0.132***	-0.071			2.155***	2.029***

Table A.5

The effect of the telegraph on modern Chinese banks: county level results.

This table reports the 2SLS estimates at the county level. Panel C reports the corresponding OLS estimates for comparison. Telegraph in 1896 is a dummy variable indicating whether a county had a telegraph station in 1896. It is instrumented by a county's distance to HMTN (in log). The 21 military centers are excluded. County controls include distance to coast (log) and land size (log); prefectural controls include the population in 1880 (log) and the number of treaty ports in 1896. Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Number of banks in 1911</i>			<i>Number of banks in 1936</i>			<i>Average growth of banks, 1897–1936</i>		
	1	2	3	4	5	6	7	8	9
<i>Panel A. Second stage estimates</i>									
<i>Telegraph in 1896</i>	0.304*	0.204	0.350	6.145***	4.183***	3.235**	0.154***	0.105***	0.081**
	(0.173)	(0.146)	(0.219)	(1.613)	(1.286)	(1.458)	(0.040)	(0.032)	(0.036)
County controls		Yes	Yes		Yes	Yes		Yes	Yes
Prefecture controls		Yes			Yes			Yes	
Prefecture FE			Yes			Yes			Yes
Observations	1,501	1,501	1,501	1,501	1,501	1,501	1,501	1,501	1,501
<i>Panel B. First stage for telegraph in 1896</i>									
<i>Distance to HMTN</i>	-0.041***	-0.046***	-0.049***	-0.041***	-0.046***	-0.049***	-0.041***	-0.046***	-0.049***
	(0.007)	(0.008)	(0.013)	(0.007)	(0.008)	(0.013)	(0.007)	(0.008)	(0.013)
K. P. F-statistic	31.818	35.268	13.787	31.818	35.268	13.787	31.818	35.268	13.787
R^2	0.026	0.076	0.295	0.026	0.076	0.295	0.026	0.076	0.295
<i>Panel C. OLS estimates</i>									
<i>Telegraph in 1896</i>	0.264***	0.252***	0.305***	3.105***	2.873***	2.985***	0.078***	0.072***	0.075***
	(0.060)	(0.057)	(0.074)	(0.544)	(0.511)	(0.563)	(0.014)	(0.013)	(0.014)
R^2	0.068	0.078	0.104	0.112	0.130	0.221	0.112	0.130	0.221

Table A.6

The effect of the telegraph on economic development through banking.

This table examines the extent to which the effect of the telegraph on economic development is explained by banks. Economic development is measured by the log number of industrial establishments in 1934 or the principal component of the three economic measures used in Table 3. Telegraph in 1896 is instrumented by the log distance to HMTN. Number of banks in 1934 refers to the log number of bank headquarters and branches in 1934. Controls include population in 1880 (log), number of treaty ports in 1896, distance to coast (log), and land size (log). Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>Number of industrial establishments in 1934</i>		<i>Principal component of economic development</i>	
	1	2	3	4
<i>Telegraph in 1896</i>	1.164** (0.533)	0.655 (0.532)	0.755** (0.311)	0.634* (0.336)
<i>Number of banks in 1934</i>		0.705*** (0.150)		0.169* (0.100)
Controls	Yes	Yes	Yes	Yes
K. P. F-statistic	24.239	18.424	24.239	18.424
Observations	266	266	266	266

Table A.7

The telegraph and information flow: evidence from news reports at the county level.

This table replicates Table 9 using county level data. Telegraph in 1896 is instrumented by a county's distance to HMTN (in log). The controls include the prefectural level population in 1880 (log) and the number of treaty ports in 1896, and the county level distance to coast (log) and land size (log). Heteroskedasticity-robust standard errors in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively.

	<i>News frequency, 1897–1911</i>	<i>News frequency, 1897–1936</i>	<i>Number of banks in 1911</i>	<i>Number of banks in 1936</i>	<i>Average growth of banks, 1897–1936</i>
	1	2	3	4	5
<i>Telegraph in 1896</i>	4.351*** (1.083)	4.743*** (1.248)	0.142 (0.163)	3.408** (1.371)	0.085** (0.034)
<i>News frequency, 1897–1911</i>			0.014 (0.009)		
<i>News frequency, 1897–1936</i>				0.164*** (0.062)	0.004*** (0.002)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	1,501	1,501	1,501	1,501	1,501
K. P. F-statistic	35.268	35.268	32.330	33.450	33.450

Appendix B. The construction of the telegraph trunk lines in the late Qing period¹

Tianjin-Songjiang Line (Line 1-2-3 in Fig. 2). In September 1880, the Zhili governor-general, Li Hongzhang, proposed to the Qing imperial court to set up a land telegraph line from Tianjin to Shanghai, thus commencing a large-scale construction project. In a memorial to the throne, Li Hongzhang talked a great deal about the military situation at home and abroad, emphasizing the significance of the telegraph to national defense, and the enormous threat posed to China by the wide gap between Chinese and foreign communications. He thought that the wide disparity in the speed of Chinese and foreign communications put China at a severe disadvantage. On this basis, Li warned his countrymen, “During times of combat, foreign countries equipped with a telegraph system could transmit military information much faster than China; the advantages and disadvantages of using the telegraph or not are quite clear.” Finally, Li Hongzhang was instructed by the Zongli Yamen (Ministry of Foreign Affairs) to “handle the situation as needed”, and hence seized the opportunity to set up the Tianjin-Shanghai line immediately to facilitate information transfer in 1881.

Songjiang-Guangdong Line (Line 3-4-5 in Fig. 2). On January 16, 1883, Li Hongzhang applied to Zongli Yamen to “attract investment to take over the coastal landlines from Shanghai to Zhejiang, Fujian and Guangdong provinces”. The construction of the line began in March 1883, but experienced delays soon after because of money problems. The imminent Sino-French War in 1883 meant that the construction of the border wire had to be undertaken first. These factors resulted in the repeated postponement of the project until March 1885. The line connected Songjiang and Guangzhou by passing through important cities and trade ports; its total length was 5,015 *li* [Chinese miles, about 2,507.5 km]. As a result of passing through these centers of trade, the revenue of the line would be protected to a certain extent, and the installation of the line, in turn, would promote the prosperity of commerce in the region.

Songjiang-Wuchang Line (Line 3-6-7-8 in Fig. 2). In the early 1880s, there was a discussion on the establishment of an additional telegraph line from Songjiang to Hankou along the Yangtze River (the so-called Yangtze River Line). Sheng Xuanhuai ultimately approved the project and required it to be fully funded by “Chinese businessmen”. The dispute over the line brewed for a year and ten months. The line began from the south bank of the Yangtze in Jiangning (Nanjing) and reached Hankou (in Hubei province) via the cities of Wuhu, Yinjiahui, Datong, and Anqing (in Anhui province), as well as Jiujiang (in Jiangxi province). Work started in July 1883 shortly after the order was given, and was completed in April and May 1884; the line had a total length of 815 kilometers.

Tianjin-Shuntian (Beijing) Line (Line 1-9 in Fig. 2). This line was the extension of the Tianjin-Shanghai line to the imperial capital. The line, which was less than 150 kilometers long, was built in two steps. First came the construction of the Jintong Line (Tianjin to Tongzhou). After the opening of the Tianjin-Shanghai Line, horses were still used to deliver

¹ This section is based on Xia’s (2012) study of the late Qing telegraph.

telegrams between Beijing and Tianjin. This situation seriously restricted contact between the central government and local governments. After tensions rose between China and France, Zeng Jize (a leading reformist minister of Qing) proposed to the Zongli Yamen to expand the Tianjin-Shanghai line to Beijing as soon as possible, saying that this move would be beneficial to both diplomatic and military affairs. However, due to the seriously conservative atmosphere in the capital, Li Hongzhang had to formally apply for the extension of the Tianjin-Shanghai Line to Tongzhou (located near Beijing) on July 17, 1883. This work was completed on September 18, 1884. As Sino-French relations were further strained in 1884, and the Zongli Yamen urgently needed real-time information regarding the war, on July 12 it approved the Jintong Line and an official telegraph bureau in Beijing. Beijing was finally connected to the telegraph network.

Tianjin-Yongping (Shanghai Pass) Line (Line 1-10 in Fig. 2). Yongping prefecture had an important military pass, the Shanghai Pass, which defended the imperial capital in the north. On May 19, 1884, Li Hongzhang proposed to set up a telegraph line from Tianjin to Shanghai Pass, reasoning that the current coastal defense in the north was weak and that the line would largely improve the defense capacity. During the Sino-French War, the project was immediately started after Li's appeal and was completed in the middle of August. The total length of the line was 267.5 kilometers, and its construction cost 31,961 silver *liang*.

Guangzhou-Taiping-Leizhou Line (Line 5-11-12 in Fig. 2). After France invaded Vietnam in 1883, the neighboring Guangxi province of China confronted high pressure in defense preparations. At the time, it took a month to deliver a message from Zhennan Guan (an important military garrison in Guangxi) to the imperial capital. For this reason, the governor-general Zhang Shusheng proposed to build a telegraph line connecting Taiping prefecture (a military center) of Guangxi to Guangzhou (an important telegraph node in south China). The line was completed in July of 1884. Later, the succeeding governor-general Zhang Zhidong extended the line to the naval fortress in Leizhou prefecture, in order to improve the coastal defense against the French army stationed in Vietnam. It was completed in early December of 1884.

Tianjin-Baoding Line (Line 1-13 in Fig. 2). During the Qing dynasty, the Zhili Governor-general and the Beiyang Minister were supposed to be stationed in Tianjin in spring and summer, and Baoding (the provincial capital) in autumn and winter. Li Hongzhang believed that Tianjin was too far from the provincial capital, and it took too much time to travel back and forth in case of a local emergency. He felt that all issues of coastal defense and those involving Westerners needed to be transmitted in timely fashion by telegraph between the two important cities. Through Li's efforts, the telegraph project began in September 1885 and was finished in a month. Beginning in Tianjin, the line passed through Jinghai, Dacheng, Wen'an, Bazhou, Xiong County, Anzhou, Rongcheng, Ansu, and Qingyuan before arriving in Baoding. It stretched for more than 150 kilometers. Expenses were noted to have been more than 19,100 *liang* of silver.

Yunnan-Chengdu-Wuchang Line (Line 8-14-15 in Fig. 2). After the end of the Sino-French War, the two sides signed the Treaty of Tianjin on June 9, 1885, which stipulated the land

border between China and Tonkin and allowed French businessmen protected by France to trade across the border. China and France immediately held further talks on specific trade issues in Yunnan, Guangxi, and Guangdong provinces. Together with this, the Yun-Gui Governor-general Cen Yuying felt that the number of negotiations between China and foreign countries was bound to increase gradually. However, when Yunnan was faced with an emergency, messages regarding the emergency had to be delivered from local counties to Nanning prefecture in Guangxi province, and then transferred to eastern Guangdong and then sent on to the capital Beijing. It took 20 to 30 days, which was very inconvenient. The Qing court began to construct a telegraph line for Yunnan province from 1886. In order to connect the other important cities in southwestern China as well, the telegraph line was extended from Wuchang (the telegraph node in central China) to Chengdu (the provincial capital of Sichuan in the southwest) before reaching Yunnan.

Jinan-Dengzhou Line (Line 2-16 in Fig. 2). The construction of the Ji'nan-Dengzhou (Yantai) line was also a result of the Sino-French War. In 1884, Li recognized the urgent need to obtain military intelligence from the French concession in Yantai. The line was first extended from Jining at the Tianjin-Songjiang line to the provincial capital of Ji'nan. Then the line was extended from Ji'nan to Yantai, passing through Qingzhou and Laizhou prefectures along the way. The line was completed in September 1887. It stretched for 78.5 kilometers, and its construction cost 7,332 silver *liang* from the Beiyang Coastal Defense funds.

Ji'nan-Kaifeng Line (Line 2-17 in Fig. 2). At the end of 1887, the governor of Henan province, Ni Wenwei, asked Sheng Xuanhuai to build a line that connected Henan to the Tianjin-Songjiang telegraph. The line started from Jining in Shandong province and stretched to Kaifeng (the capital of Henan province). It was completed in March 1888.

Jiujiang-Guangzhou Line (Line 5-7 in Fig. 2). In 1888, Sheng Xuanhuai and Li Hongzhang built a line connecting Guangzhou to Jiujiang, an important pass of the Yangzi River in Jiangxi province. The construction of the line was complementary to the Shanghai-Guangdong line in case the latter broke down on occasion. The line was completed in 1881, and its length was 725 kilometers. It also linked Nanchang, Zhangshu, Ji'an, Ganzhou, Yuling and other places, and became a major trunk line connecting Guangdong on the south coast to the Yangzi River.

Tai ping-Yunnan-Yongchang Line (Line 11-14-18 in Fig. 2). In 1886, Zhang Zhidong, the governor-general of Guangdong and Guangxi provinces, proposed the construction of a wire from Nanning in Guangxi to Yunnan province, but construction could not be started immediately because of the shortage of funds. Later, Zhang Zhidong persuaded Guangdong and Yunnan province to cooperate vigorously. The line was finished in 1889. A total of 15,939 silver *liang* was used to lay 374.5 kilometers of wire. The Yunnan-Yongchang line was set up by the general-governor of Yunnan and Guizhou in response to the tense military situation on the southwestern frontier after the British occupied Myanmar. The line was also finished in 1889. It cost 13,707 silver *liang* and had a total length of 523.5 kilometers.

Shuntian (Beijing)-Baoding-Xi'an-Lanzhou Line (Line 9-13-19-20-21 in Fig. 2). On October

15, 1889, Yang Changjun, the governor-general of Shaanxi and Gansu provinces, set up the Xi'an-Jiayuguan line, thus opening up construction of the telegraph in the northwestern region. In Yang Changjun's view, the telegram had been continuously extended in the east, south, and north of China. Its effects had become increasingly apparent, but it had not been set up in the northwest, so it was urgent to construct it in order to improve communications in this area. What was particularly important was that the border affairs in the region were becoming more and more complicated. First, popular uprisings occurred from time to time. Secondly, there were constant disturbances from the outside. After China took back Ili, the number of Russians traveling to and from Xinjiang did not abate. Kashgar bordered British-held north India, from which it was separated by the tribes of Bulut and Kankuti, and there were increasingly frequent negotiations. Xining prefecture, which was subordinate to Gansu, and the territory of Qinghai lay on the way to Tibet, and it was inevitable that trouble would arise when the British entered Tibet for trade. Once war broke out in India and Tibet, telegrams from the court only reached as far as Sichuan, and the information was not timely. The line was completed in December 1890.

Wuchang-Xi'an Line (Line 8-20 in Fig. 2). This line was constructed as the backup for the Beijing-Shanghai Line during the First Sino-Japanese War. With Weihai (in Shandong Province) controlled by Japan in 1895, communication between the north and south of the Qing empire could be interrupted if the Beijing-Shanghai Line was blocked. The Qing government thus extended the wire to Xi'an in the west, in order that information could still be sent to Shanghai and south China by detouring through Xi'an and Wuchang. The line was built in 1895, with a total length of 585 kilometers.

Appendix C. The construction of the HMTN and MSTN

This section introduces the construction of the hypothetical military telegraph trunk networks, HMTN and MSTN. Given that the early telegraph was built mainly for military purposes, we connect the 21 military centers of the Qing dynasty into a hypothetical trunk network. The HMTN is based on the least cost in constructing a single line that connected two military centers, whereas the MSTN (Minimum Spanning Tree Network) is based on the minimum construction cost of the entire telegraph system of Qing China. We elaborate on the constructions of the two networks below.

HMTN:

For each telegraph line that connected two military centers, we generated a hypothetical line with the least construction cost. Ideally, the path of least cost is the straight line. But in reality, the cost of building telegraph lines is subject to geographical barriers, particularly difficult terrain (mountains) and rivers. For example, in the absence of a bridge, it is difficult to stretch the line across the river. Likewise, it is also costly to bring the line over huge mountains. As a result, the least cost line may not be straight but rather be shaped by topographical and hydrological characteristics.

To calculate the least construction cost of the telegraph lines, we obtained information on topography (slope and fluctuation) and hydrology from the Shuttle Radar Topography Mission (SRTM)². Using ArcGIS, we organized the data at the 1km × 1km grid cell level. For each grid cell, we calculated its construction cost based on the cost function of building roads in China (Tang and Yang, 2012)³:

$$\text{Cost} = 0.5 \text{ hydrology} + 0.3 \text{ slope} + 0.2 \text{ fluctuation}$$

Fig. A.7 provides the graphical distribution of the construction cost. Next, we use the cost distance algorithm in ArcGIS to compute the least-cost path between two military centers. This yields an accumulative cost raster and a directional backlink raster for each of the 21 military centers. For a given military center, we input the accumulative cost raster, the directional backlink raster, and the target nodes (the other 20 military centers) into the cost path algorithm in ArcGIS, and then obtain 20 least-cost paths. Repeating this procedure for every military center generates the least cost paths among a total of 210 [(21 × 20)/2] bilateral pairs of the targeted military centers. Finally, we choose the paths that are closest to the real telegraph lines in 1896 as our HMTN (Fig. 2).

MSTN:

We assume that the Qing government tried to minimize the construction cost of the whole telegraph network. Accordingly, we employed the minimum spanning trees method to generate the least cost telegraph network for the whole country. The spanning tree was constructed by a two-step procedure. First, we computed the least construction cost path of each hypothetical telegraph line that connects any two military centers. The method in computing the least construction cost path is the same as that of HMTN, except that we extract the aggregate construction cost for all possible bilateral least-cost paths.

² Available at <http://www.gscloud.cn/sources>.

³ See also Faber (2014) for the application of this method in constructing the least cost path of the Chinese highway system. There is no available construction cost function for building telegraph line.

Next, using the Greedy Algorithm method (Kruskal, 1956), we generated the overall least-cost network that connects the 21 military centers (nodes). Specifically, this method starts with a node and calculates the minimum cost paths from this node to all the other nodes, and repeats this process for all the nodes. On this basis, it computes the optimal global solution from the local optimal solutions. An exception in our context is that we treat the two coastal lines (Tianjin-Songjiang Line and Songjiang-Guangzhou Line) as given, i.e., not reshaped by the spanning trees. This is because the two lines were the earliest telegraph lines and hence the starting point (nodes) from which the government expanded the telegraph network to inland areas. Specifically, we keep the least construction cost paths for these two coastal lines while calculating the MSTN for the other lines.

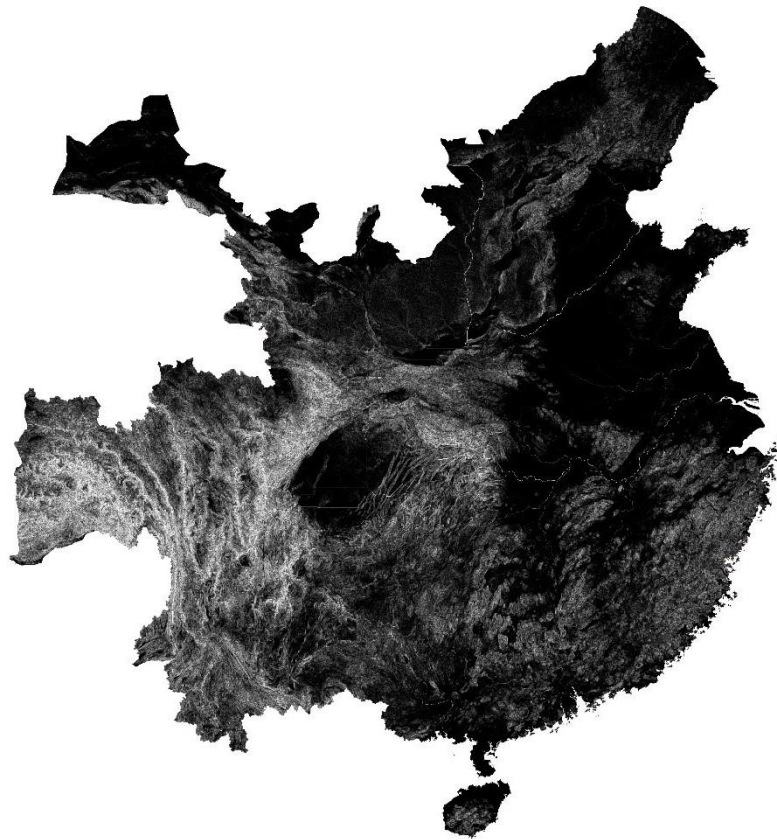


Fig. A.7. Telegraph construction cost based on topography and hydrology. This figure displays $1\text{km} \times 1\text{km}$ grid cell construction cost based on topography and hydrology. The dark color denotes a lower cost.

Appendix D. Historical sources

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KMT Central Executive Committee, 1935. Quanguo Renmin Tuanti Tongji (Statistics on Nationwide People's Organizations).

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