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# Information and Price Convergence: Telegraphs in British India

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## Abstract

In contrast to the literature on railways, there have been few empirical studies of the impact of telegraphs, another revolutionary technology, on price convergence. The few that exist measure the impact of telegraphs on commodity price differences between countries in the presence of a well-established efficient transportation system: ocean shipping. This paper estimates the impact of telegraphs within a developing economy, British India, with sparse, inefficient transportation. We use a rich dataset of rice and wheat prices for 192 districts between 1862 and 1920. Over 14,000 district pairs are linked by telegraph in the sample. We obtain strong evidence that, even in this context, telegraphs significantly reduced grain price dispersion before railways appeared. There were also spillover effects on neighboring districts. The combined impact of railways and telegraphs still cannot explain most of the convergence in our sample. However, the results highlight the potential importance that communication advances had on late 19$^{th}$ century market integration in less developed economies.



**Keywords:** Price convergence; information; telegraph; British India; grain prices

**JEL Classification:** L96; N75; O13; O18; O38

# Informatıon and Prıce Convergence: Telegraphs in Brıtısh Indıa[1]

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## Introduction

There is an extensive literature on the impact of railways on economies (Fogel, 1964; Fishlow, 1965; Donaldson and Hornbeck, 2016). That is to be expected, given the path-breaking significance of that technology. But much less research has been done on the economic impact of another transformative 19th century invention: the telegraph. Sometimes called the Victorian Internet, it dramatically expanded global access to current information. Before telegraphy appeared, it could take London a week to get news from Berlin, 10 days from New York, and 30 days from India (Standage, 1998; Juhász & Steinwender, 2018). Telegraphs reduced those times to less than a day.

Economic theory predicts that one effect of this new technology should be price convergence. Current reliable information about price differences across markets should reveal arbitrage opportunities and encourage the movement of goods to higher-price markets. Yet only a few studies have rigorously tested this proposition.

This paper uses a rich panel dataset from British India between 1862 and 1920 to estimate the impact of telegraphs on wheat and rice price dispersion. Controlling for railways, we find that telegraphs had a significant and economically meaningful impact on price differences across districts. This is especially true when the model includes spillover effects from telegraphs and railways on neighboring districts. The telegraph effect in the absence of railways was also larger in the presence of more efficient transportation options, such as along the Ganges River/Grand Trunk (GT) road corridor.[5] Estimates suggest that the introduction of telegraphs reduced colonial Indian grain price dispersion by as much as 7-

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[5] The GT road is a two-thousand-year-old trade route that originates near Calcutta and runs through Allahabad, Delhi, Lahore, and Peshawar. From Calcutta to Delhi it parallels the Ganges.

13%. This is despite the fact that pre-rail transportation options in the subcontinent were slow and expensive. The results suggest that information flows may have had important effects on market integration even in less developed economies in the late 19$^{th}$ century.

The next section briefly surveys the literature on the historical effects of railways and telegraphs on price dispersion. Descriptions of the Indian telegraph system, wheat and rice markets, and transportation infrastructure follow. The model, data and estimation are then presented. A conclusion sums up what we have learned.

**Literature**

Numerous studies examine the historical effects of new transportation technology on price dispersion (Metzer, 1974; Slaughter, 2001; O'Rourke and Williamson, 1999; Dobado and Marrero, 2005; Andrabi and Kuehlwein, 2010). They found that the introduction of railroads and steamships in the nineteenth century significantly shrank price differentials within the United States, Germany, Russia, Mexico, and India. Jacks (2006) also concluded that railways reduced trade costs between 19th century cities.

Research on the impact of telegraphs on price dispersion is much sparser. DuBoff (1983) noted that price differences in major eastern United States markets for some farm products shrank as much as 50% between 1844 and 1854. Because this period predated the widespread use of railways in transporting farm commodities, he attributed the shrinkage to an expanding telegraph system. Field (1998) reported that regional differences in stock and bond prices in the United States virtually disappeared following the introduction of telegraphs to securities markets. Collins (1999) hypothesized that the decline in several British/Indian commodity price ratios between 1873 and 1913 was likely due to transportation and communication advances, including the telegraph. Ejrnæs and Persson (2010) found that after the United States and Britain were connected by telegraph in 1866, the wheat trade between Chicago and Liverpool became efficient in the sense that the difference in wheat prices shrank to the cost of transport between the two cities. Chilosi and Federico (2015) estimated that the laying of a telegraph cable between India and Britain in 1870 could explain about a quarter of the fall in commodity price differences between them from 1815-1913.

Steinwender (2018) concluded that the transatlantic telegraph lowered average cotton price differences between the United States and Britain by 35%.[6]

So, there are only a few studies that have estimated the historical impact of telegraphs on commodity prices dispersion, and they focused on prices between countries separated by major bodies of water. In each case, efficient shipping methods were available to take advantage of price differences. The studies also focused on the impact of a single telegraph connection. This paper, in contrast, tests for the effects of telegraphs in an emerging market, British India, with poor transportation options before railways arrived. A priori, it is not at all clear that information about price differences in that setting will induce arbitrage. As such, the hurdle for obtaining significant results is much higher. Our approach also differs in that we observe the impact of over 14,000 telegraph connections. That allows us to measure the impact of telegraphs on price dispersion with a high degree of precision.

## Indian Telegraph and Railway Systems

Interest in bringing telegraphs to India began almost as soon as commercial versions appeared in Britain in the late 1830s. In 1839, William O'Shaughnessy built a simple 30-mile experimental telegraph line in the Calcutta Botanical Gardens.[7] In 1847, he was awarded a government contract to construct an 80-mile line from Calcutta to Diamond Harbor to facilitate boat traffic. It opened in 1851. The following year he convinced Lord Dalhousie, Governor-General of India, to connect India's main cities by telegraph. By 1855, over 3,000 miles of telegraph lines crossed the subcontinent, linking Calcutta to Agra, Bombay, Peshawar, and Madras (see Figure 1A and Table 1). By 1860, telegraph mileage had tripled. Part of the jump in mileage came after the telegraph proved itself to be invaluable during the 1857 Rebellion by providing real-time information to the British military.

Figure 1B shows that by 1872 the network had branched out considerably through the interior.[8] There were also by then multiple paths for telegraphs to connect most large

[6] In related research, Andrabi, Bharat and Kuehlwein (2020) demonstrated that another communication technology, the mail, contributed to price convergence in British India. Jensen (2007) and Aker (2010) found that the spread of cell phones has recently brought fish and grain prices together in India and Niger respectively.

[7] See Gorman (1971) and Beauchamp (2001) for detailed histories of these events.

[8] The maps do not show Burma, also part of British India, but by 1872 a line ran from Rangoon to Calcutta.

cities, improving reliability. By 1881, mileage had doubled relative to 1860, and by 1920 it had further quadrupled. By the end of the 19th century, India, with over 50,000 miles of lines, had the largest telegraph network in the world outside the United States and Europe.

From the start, telegrams in India were relatively cheap, costing 25% to 50% less than messages traveling comparable distances in the United States or England (Shridharani, 1953). That derived in part from the government operating the system as a utility, focused more on providing a public service than earning a profit.[9] The speed of transmission was slow at first. In 1868, it took 18 hours for a telegram to travel from Calcutta to Karachi. But by 1872, the time had dropped to two hours, and by 1877 it took less than an hour (Wenzlhuemer, 2013). Transmission times to other cities also dropped sharply. In 1872, the government stopped charging based on distance. In 1883, the telegraph and postal departments merged, and post offices started offering telegraph services. Over time, this greatly expanded the number of telegraph offices. For instance, in 1900 1,612 of the 1,851 government telegraph offices were in post offices. (Administration Report, 1903/04)

The building of railroads began at about the same time, starting in Bombay in 1853 (Hurd and Kerr, 2012). However, the growth in track mileage was much slower than for telegraphs, due to the extra time and cost involved. In 1860, telegraph mileage exceeded railway mileage 14 to 1. Afterwards, railway construction accelerated, so that from 1881 through 1920 the ratio was closer to 2 to 1. Contrary to telegraphs, most railways initially were privately owned and run. Beginning in the 1880s, however, the Government of India started purchasing private railways, though they let some companies continue to operate them (Bogart and Chaudhary, 2015).

The motives for building the two systems were similar. Railways were crucial for transporting commodities to port for export, and for moving troops and military equipment around the colony. Somewhat belatedly, they were also built as a protection against famine (MacPherson, 1955; Bharat, 2012).

For telegraphs, military and political considerations were paramount. Wenzlhuemer (2013, p. 236) claims the system "catered to the needs of the administration and the military in the first place." Shridharani (1953, p. 20) writes that these needs were "never far from the British mind." Dalhousie referred to the invention as "an engine of power," and asserted that in one Indian conflict, "it made all the difference between defeat and victory." (Shridharani

[9] For example, from 1868-73, the Telegraph Department consistently lost millions of rupees. It wasn't until 1878 that the department made money. (Shridharani, 1953)

1953, p. 20). The technology was extremely useful in administering such a large colony. It made possible timely conversations and decisions by distant administrators. After the first telegraph line between Bombay and London was completed in 1870, communication between the British government and colonial administrators also dramatically improved.

Commercial considerations also came into play. Indian newspapers lobbied for the construction of telegraph lines so they could obtain current news. Railroads benefitted from being able to communicate information about arrival and departure times. Businesses producing tradable goods had an interest in nearby market conditions. Indeed, it has been noted that the network was set up to connect both "administrative and business centres" (Wenzlhuemer 2013, p.225). Still, economic factors seem to have been secondary to the political and military exigencies of running an empire. That is one reason, for instance, that the network was slow to expand around Madras, which was far from hostile borders (Ghose, 1995).

**Wheat and Rice Markets**

Wheat was grown primarily in cooler northern India in the Punjab, United Provinces, and North-West Frontier Provinces. In 1895, those provinces contained 63% of total wheat acreage in India. Due to greater water needs, most rice was planted along the east coast in Bengal and in the tropical south in Madras and Burma. Those three provinces made up 75% of rice acreage. Rice was the more important crop, with three times the acreage of wheat (Statistical Abstract, 1896). Approximately a third of the population consumed rice compared with one-twelfth consuming wheat (Connell, 1885; Hunter, 1886). Both grains were exported, but more than 90% of the production of both crops was consumed internally. Wheat and rice prices were generally lower in the provinces producing them. There were two rice seasons during the year: the early crop harvested between July and September and the winter crop harvested between November and January. Wheat was typically planted in the winter and collected in the spring, before the summer monsoon.

**Transportation Infrastructure**

At the time of the arrival of telegraphs, paved roads were rare and unpaved roads were virtually unusable during the rains. (Banerjee, 1966) Pack animals were employed, but grain is bulky, limiting how much they could carry. Travel was slow, with some caravans taking months to reach their destinations. Spoilage was an issue. A concerted government effort to build better roads begun in the 1850s, however, did eventually lead to the use of more efficient bullock carts. (Derbyshire 1987) River transport was confined to a relatively small number of rivers, and was risky and seasonal. Traveling upstream before steamboats appeared was difficult. Arrival times could be unpredictable, with bad weather wreaking havoc on schedules. Piracy was a threat on both land and water, and insurance was costly. (Hurd, 1975) So pre-rail transportation options existed, but they were far from ideal.

**Theory**

We assume a simple gravity model of price dispersion. Arbitrage ensures that grain prices between cities never differ by more than the cost of transporting grain between them. Telegraphs assisted in this process by alerting producers and middlemen to arbitrage opportunities. They also reduced transportation costs by improving coordination and eliminating inefficiency in rail and shipping enterprises. Scholl (1998) argues that telegraphs improved the efficiency of tramp shipping by better informing shipping companies of demand around the world for their services. Lew and Cater (2006) demonstrate that these efficiencies significantly boosted international trade in the late 1800s. Field (1992) contends that improved scheduling from telegraphs significantly reduced capital requirements for railroads by enabling single-track systems with turnouts instead of double-track systems.

Our measure of price dispersion is the absolute value of the difference in log prices ($AbsDif_{ijt}$) between districts i and j in year t: $|p_{it} - p_{jt}|$. It is calculated for each district pair in the two samples. It approximately measures the percentage price difference between them. The main covariates are indicator variables for four types of railway and telegraph connections between pairs: RailOnly, where the districts are linked by rail but not by telegraph; TeleOnly, where they are linked by telegraph but not by rail; RailAndTele, where they are linked by both; and OneTeleOneRail, where one district only has a railway and the other only has a telegraph. The default case is where at least one district has neither a railway nor a telegraph.

The baseline model is then:

$$AbsDif_{ijt} = \alpha + \theta_{ij} + \gamma_t + \beta{*}RailOnly_{ijt} + \delta{*}TeleOnly_{ijt} + \lambda{*}RailAndTele_{ijt} + \varphi{*}OneTeleOneRail_{ijt} + \mu_{ijt} \quad (1)$$

Here $\theta_{ij}$ is a district-pair fixed effect, $\gamma_t$ is a year fixed effect, and $\mu_{ijt}$ is a random error term. The district-pair fixed effect captures time-invariant factors that might influence price differences between districts including geography, soil quality, climate, and the distance separating them. The time fixed effect captures colony-wide changes in price dispersion, perhaps due to variations in weather, institutions, government policies, and technologies other than railways and telegraphs. Standard errors were clustered at the district-pair level to allow pair-specific disturbances to be correlated over time.

## Data

The sample runs from 1862 to 1920. Annual retail wheat and rice prices are expressed in rupees per ser (2.057 lbs.), and are averages of prices from fortnightly surveys at district headquarters. They are reported in the 1896 and 1922 issues of *Prices and Wages in India.* A few districts were dropped due to insufficient data. The year a railway arrived at or near (within 20 miles of) a district headquarters comes from the 1947 edition of *The History of Indian Railways.*[10] The year a telegraph arrived at or near a district headquarters comes from annual *Administration Reports of the Indian Telegraph Department*. The wheat sample contains 158 districts, while the rice sample has 192 districts, including all of the wheat districts plus 20 districts from the south (Madras), 10 districts from Burma, and 4 districts from the north. Eight districts were dropped after 1900 because of missing information on whether they acquired telegraphs after that year.

Computing log price differences for each possible district pair for each year produced 650,161 observations for wheat and 980,192 for rice. Data on how close districts were to the coast, Ganges River, or GT road were obtained from historical and current maps of India.

[10] Sometimes railway stations were located just outside the city.

Figures 2A and 2B plot the growth in railroads and telegraphs against a three-year moving average of the dependent variable, AbsDif. The rapid decline in price dispersion is apparent. Mean log wheat price differences between district pairs fell from 0.48 in the early 1860s to about 0.17 from 1905-20. For rice, log dispersion fell from 0.52 to about 0.20. In both cases, price dispersion fell by over 60%. The rising number of railways and telegraphs makes it clear why they are considered likely candidates to explain that decline. Price dispersion fell fastest in the first three decades of our sample, precisely when railroads and telegraphs grew the fastest. By 1900, most of the districts in the sample had both telegraphs and railroads, and that is also when price dispersion leveled off. The growth in telegraphs is especially concentrated in the first half of the sample, suggesting that it may have played a large role in the early drop in price dispersion.

One complication we encountered is that although we have excellent data on government telegraph stations, we have no data on private telegraph stations. Railroads built their own telegraph system alongside their tracks (Wenzlhuemer, 2013). Building telegraphs along railroad tracks was efficient and common at that time, also occurring in the United States and Britain (Standage, 1998; Beauchamp, 2001). The result was two independent telegraph systems "competing against each other for the favor of the public" (Wenzlhuemer, 2013, p. 227). In some cases, the two sets of lines lay virtually on top of each other. They also did not usually share messages.

What this implies is that when two districts were connected by rail, they were also probably connected by private telegraph. That makes it impossible to measure the impact of just a railway connection. But we can measure the impact of just a telegraph connection. This is also a reason to include the variable *OneTeleOneRail* in the model. Having a railroad in one district probably meant having a private telegraph in that district. That telegraph could then be linked to another city with both private and government telegraphs. Price information which is shared in that city could then be conveyed by government telegraph to a district without a railroad. The connection would be more convoluted than a direct link between two districts, but information could have flowed this way. For the remainder of the paper, telegraphs will refer to government telegraphs only.

Table 2 contains summary statistics of the data. Average log price dispersion is 0.25-0.29. Price differences are about 15% higher in our rice sample, perhaps due to that sample including distant districts in south India and Burma. Having a rail link but no (government) telegraph link occurs only 3% of the time, while having a telegraph link but no rail link occurs 21-28% of the time. In both samples, about half the district pairs had both links. The two "close" variables will be defined later. *TelexGangesGT* is the product of *TeleOnly* and a variable indicating whether both district headquarters were on the Ganges or the GT road. *TelexCoast* interacts *TeleOnly* with whether both district headquarters were close to the coast.

A priori, we would expect railway connections to lower price dispersion more than telegraph connections. Railways provided both information about profit opportunities and the means to exploit them. Telegraphs only provided information. Without railways, it should generally have been costlier to act on those opportunities. In a few regions early in our sample, alternative transportation options, particularly riverboats, may have been cheaper than railways (Derbyshire 1987). But as rail charges fell, railways quickly became the cheapest means for transporting grain in India. For *RailAndTele,* it's not clear that having railways and telegraphs would be any different than just having railways, since most railways came with private telegraphs. But there could have been cost or reliability differences between the two telegraph networks. Finally, *OneTeleOneRail* may, as explained, facilitate arbitrage, but only in a roundabout way. That effect then should be small.

**Results**

*Baseline Regressions*

Table 3 contains our baseline results. Columns (1) and (3) contain a preliminary specification with only railway and telegraph connections. The connections are not mutually exclusive. Both railway estimates and one telegraph estimate are highly statistically significant and have the anticipated signs. The other telegraph estimate is insignificant. Having a railway connection lowers price dispersion by 3-5%, while a telegraph connection lowers it by 0-3%. As predicted, railways reduce price dispersion more than telegraphs. The effects on rice prices are larger for both technologies. The specification suffers, though, from not allowing the impact of telegraphs to vary with whether there is a railway connection.

In columns (2) and (4) our model is introduced. There are several noteworthy results. First, considering all four cases is important because the estimates differ significantly between them. Both technologies enter significantly for both grains, but the telegraph effect on wheat prices is not economically significant. Railways matter more than telegraphs. In the rice sample, the combination of railways and telegraphs is larger than the effect of railways alone, which is possible. However, that relationship flips in the wheat sample. The combination of one rail and one telegraph seems to matter. For rice prices, the effect is indistinguishable from a telegraph link, which is plausible. But for wheat prices, the effect is oddly larger than the telegraph effect. The explanatory power of the model as measured by the adjusted R2 is pretty high for panel data, in part because of our many fixed effects variables. Finally, the rice estimates are larger than those for wheat, especially for telegraphs. So, although these results confirm that telegraphs affect price dispersion, some of the relative magnitudes are puzzling.

One key difference between the samples is that the rice sample is much larger and more spread out than the wheat sample, due primarily to the inclusion of districts in Madras and Burma. To determine if that might be the reason the telegraph estimates differ by grain, we omitted Madras and Burma from the rice sample (not displayed). However, the results were largely the same. Alternatively, the larger telegraph effects for rice may be related to where the grains were produced, with rice grown along the coast and wheat grown in the interior. Perhaps interior terrain challenges limited the ability of wheat producers to exploit profit opportunities uncovered by telegraphs. In any case, we have more confidence in the estimates for rice prices because that sample is larger and more complete.

*Robustness Tests*

We begin by considering the issue of endogeneity. One problematic scenario for our estimation would be if growing districts were more likely to be connected to the telegraph grid. If growing districts were also trading more with other districts, that might reduce inter-district price dispersion. The result would be a spurious negative correlation between telegraph links and price dispersion, due to both of them being correlated with this third factor, income.

To test for that we included estimates of real district income from Donaldson (2018). That reduced the number of observations in both regressions by almost 90%. The data are available for only 123 districts in the wheat sample and 146 districts in the rice sample. They also only stretch from 1870 to 1914, and the coverage before 1884 is spotty. The results are in column (1) in Tables 4 and 5.

Income enters negatively and very significantly in the wheat regression, as expected. However, it comes in positively and weakly significantly in the rice regression. In both samples, though, the negative coefficients for *TeleOnly* grow, the opposite of what would be predicted in the above scenario. In the wheat regression, the coefficient grows considerably. In both samples the *TeleOnly* estimates remain highly significant. So, there is no evidence in these regressions that endogenous telegraph placement is responsible for our telegraph effects.

The second test only utilizes data from 1872 onwards. That is because price collection methods before then were not standardized across India (Fenski and Kala, 2017). The results are in column (2) of both tables. The estimates for TeleOnly grow in both samples, suggesting that a telegraph link reduces price dispersion between 1.5 and 4.5%.

Then we tested whether a small number of unusually large price differences might be strongly influencing our results. So we omitted the thousand largest values for *AbsDif* in both samples. Column (3) shows that the estimates for all variables reduce slightly. This makes sense because by removing the largest price dispersion values, we have also removed from the system the strongest incentives for arbitrage. Yet, all coefficients remain significant at the 1% level.

Finally, we investigated whether markets with a large number of missing prices might be distorting our results. Missing observations for specific district-pairs could indicate that those markets are thin in the sense that prices are based on a small number of transactions. The quality of those data may therefore be poor. So, we excluded district pairs that had no price data in at least 18 years, so they had less than 40 years of data. Both samples shrink less than 10% in this case, reflecting the fact that most pairs in the two samples had a high number of observations. The results in column (4) of both tables display no major effects from excluding thin markets. As a whole, therefore, our baseline telegraph results hold up under alternative specifications, and, if anything, grow in magnitude.

*Close Railways and Telegraphs*

Next, we considered the possibility that railways and telegraphs may also affect neighboring districts. Information from, say, telegraphs about profit opportunities could spread by word of mouth to nearby districts, especially if the districts traded with each other.

If so, districts without railways or telegraphs might still experience price convergence if close neighbors acquired them.

We constructed two variables to account for these spill over effects. We defined "close" as being within 100 miles of another district's headquarters. The indicator variable *CloseRail* denotes district pairs not linked by rail or by telegraph, but with a) both districts close to districts with railways, or b) one district with a railway and the other close to a district with a railway. The indicator variable *CloseTele*, is the telegraph analog to this: district pairs without rail or telegraph links, but with a) both districts close to districts with telegraphs, or b) one district with a telegraph and the other close to a district with a telegraph.[11] Since having a railway or telegraph probably has a bigger effect on a district's price than being close to a district with one, we expect our "close" estimates to be smaller than the *RailOnly*, *TeleOnly*, and *RailAndTele* estimates.

The results are in Table 6. Both of the close variables enter quite significantly in both regressions. The previous variables all remain significant. As predicted, the close estimates are smaller than those for rail or telegraph links. The size of the rail and telegraph coefficients grow substantially with the inclusion of the close variables. The telegraph estimates in particular grow markedly. The negative impact of a telegraph link in the absence of railways on price dispersion is now estimated to be 7-13%. The growth in both rail and telegraph estimates derives from the fact that by including close variables in the regressions, we are now excluding them from the default case in the regression. Since the close variables reduce price dispersion, their removal increases average price dispersion in the default case. Relative to that case, railways and telegraphs, then, have larger effects.

Also noteworthy is that the odd finding in Table 3 that the *RailOnly* effect in the wheat sample is larger than the *RailAndTele* effect is greatly attenuated here. The gap shrinks from 70% to 25%, though the difference is still significant. The puzzling finding from the baseline regressions that the *OneTeleOneRail* coefficient is much bigger than the *TeleOnly* coefficient in the wheat sample is reversed here. Now the effects of *OneTeleOneRail* in both samples are small, as predicted. Rice estimates continue to exceed wheat estimates.

[11] To avoid adding too many variables, we did not add variables that mixed close railroads and close telegraphs (e.g., one district close to a railway and the other close to a telegraph). For the same reason, we did not make the two close variables mutually exclusive; a district pair could have both close telegraphs and close railways.

*Alternative Transportation Networks*

Price information provided by telegraphs is not helpful if there is no economical way to get grain to higher-price markets. That suggests that the impact of telegraphs on price dispersion in the absence of railways depended on whether viable alternative transportation options existed. As discussed earlier, moving grain by road or river could be slow and expensive. However, the GT road was well maintained, and the Ganges supported significant boat traffic. The coast was also serviced by ships, especially close to big ports.

To capture those options, we created two variables. *TelexGangesGT* interacts *TeleOnly* with a variable equal to one if both districts were on the Ganges or GT road. The Ganges and GT road overlap often between Delhi and Calcutta, so we combined them. Its anticipated sign is negative, enhancing the effect of a telegraph connection on price convergence. *TelexCoast* interacts *TeleOnly* with a variable that measures whether both districts were close to the coast or not. Its sign will depend on whether shipping is cheaper or more expensive than the default, which would be primarily (non-GT) road transport.

The results are displayed in Table 7.[12] As expected, being close to the Ganges or GT road strengthens the negative effects of telegraphs on price dispersion. However, even in that case telegraphs are not as powerful as railways, which makes sense. The coastal variable is not significant in the wheat sample and is significantly positive in the rice sample. The fact that its only significant estimate is positive is not that surprising. Donaldson (2018) combined road, rail, river and coastal trading routes and salt prices to estimate the average cost of these transportation modes during that era. He found that average transport costs per ton kilometer were noticeably lower by road than by ship. High shipping costs would impair the ability of telegraphs to bring prices closer together along the coast.

*Interaction with Distance*

A final test of the model examines whether telegraph effects shrink with distance. That should hold for two reasons. At a high enough distance, it should not be profitable to arbitrage price differences, because transportation costs would be too high. But even if it was profitable, arbitrage should only reduce the price difference to the cost of transporting goods between districts. A greater distance between them would mean higher transportation costs, limiting the reduction in the price gap.

[12] The telegraph estimates were unchanged when analogous interaction terms for railways were added.

Table 8 contains the results of adding an interaction term between distance and *TeleOnly* to both regressions. As anticipated, the interaction term is significant and positive. At close proximity, the telegraph effect grows. But at significant distances, such as 1000 miles, the effects shrink by several percent. The estimates suggest that telegraphs could have reduced price differences over surprisingly great distances.

We also experimented with a variable that measured whether the two districts in the pair were from the same province. If provinces were very different, it could have been easier to trade within provinces than across them. However, controlling for the distance between the two districts, that variable did not significantly impact the effect of telegraphs on price dispersion in either sample.

**Contributions to Price Convergence**

With these estimates, one can simulate the impact of the revolution in railways and telegraphs on price convergence within our sample period. We multiplied the coefficients in Table 6 by the mean values of each variable for each year and added them up to give us an annual series. We added constants to normalize each series to the actual three-year moving average log price difference in 1864. The two series estimate the impact of the increasing number of railway and telegraph connections on price dispersion over time. They are plotted in Figures 3A and 3B.

The figures indicate that the combined impact of railways and telegraphs over our sample period is roughly minus four percent for wheat prices and minus eight percent for rice prices. Their contributions to the price convergence observed in our two samples are somewhat larger. For wheat, railways and telegraphs can explain about 15% of the 56% drop in price dispersion between 1862 and 1920. For rice, they can explain about 28% of the 54% drop. So, most of the convergence we observe cannot be explained by these twin technologies.

One reason the effects are not larger is that most of the district pairs at the start of our samples were not connection-free. For the rice sample, 2% were connected by rail in 1862-1864, 20% were connected by telegraphs, 18% had a close rail connection, and 56% had a close telegraph connection. So, by 1862, railways and telegraphs were already significantly depressing price dispersion. The estimates presented above just measure the increases in those price depressing effects between 1862 and 1920.

Of course, the estimated impact between 1850 and 1920 would be significantly larger, since in 1850 there were no railway or telegraph connections. If the coefficients in Table 6 also applied to the years 1850-1862, the effect of the two technologies by 1920 would have been to reduce price dispersion by 9-17 percent. The effects approximately equal the coefficients on *RailAndTele* in both samples, because by 1920 almost all districts had a telegraph and a railway. Even without railways, telegraphs would have reduced price dispersion by 7-13%, not an insignificant amount.

## Conclusion

This paper demonstrates that the introduction of telegraphs in the early 1860s meaningfully contributed to price convergence in one important part of the developing world: British India. Data from wheat and rice markets strongly support this hypothesis. In the absence of railways, telegraphs had effects on price dispersion that were statistically and economically significant. The effects grew in the presence of efficient transportation options such as well-maintained roads and navigable rivers. There were important spill over effects as well, broadening the impact of the new technology.

These effects occurred despite weak infrastructure in both land and water transportation. The results are particularly relevant given how much of the world at that time was less developed and had poor infrastructure. The telegraph effects in India were not long-lived because they were superseded by a vast railway system. But most developing countries at that time did not have extensive railway systems, though they would have had telegraphs. Our findings suggest that the appearance of telegraphs in the middle of the 19$^{th}$ century significantly contributed to price convergence in those parts of the world. Confirmation of these effects in other emerging 19$^{th}$ century markets would be quite useful.

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Figure 1A: Telegraph Network in 1855

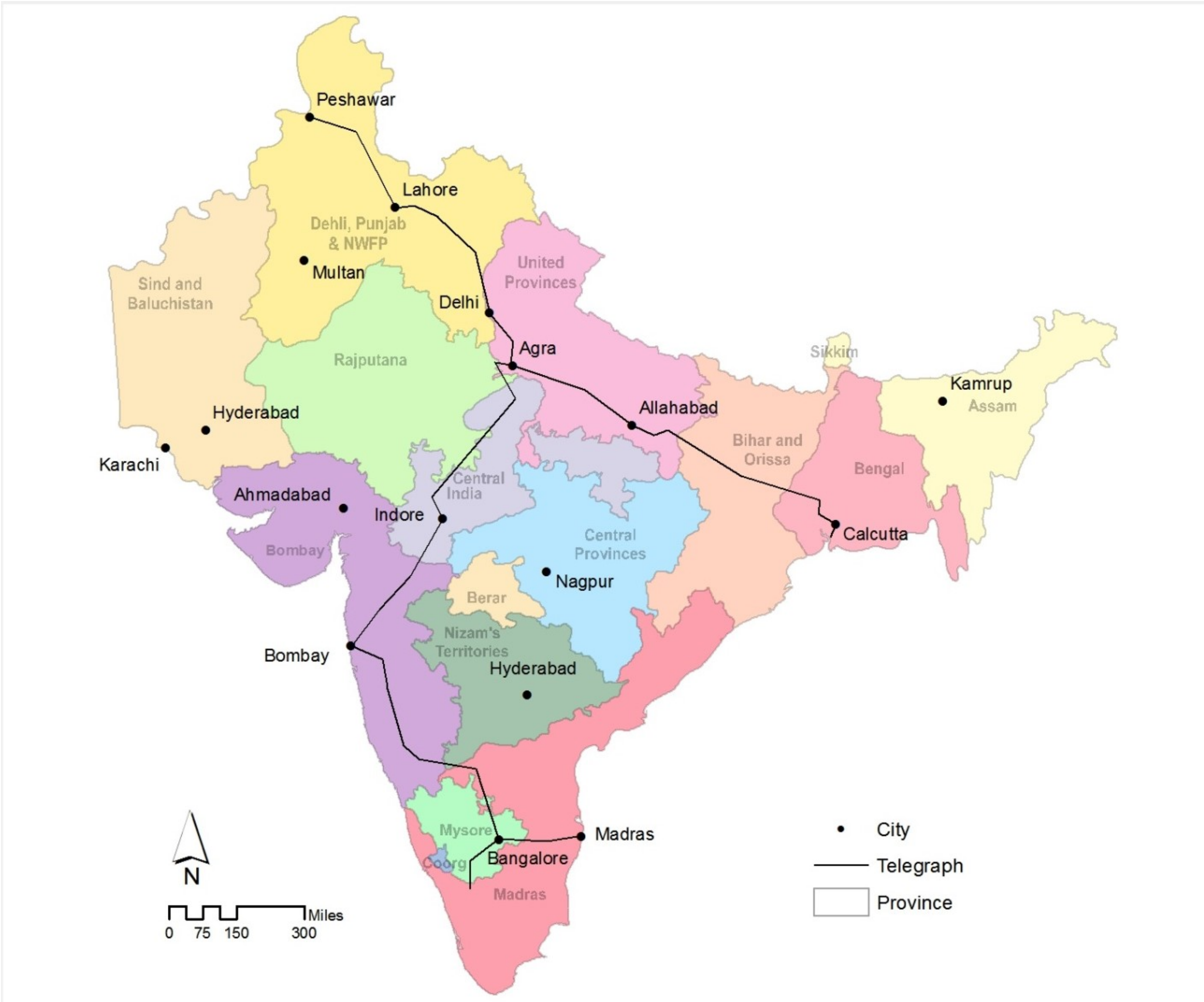
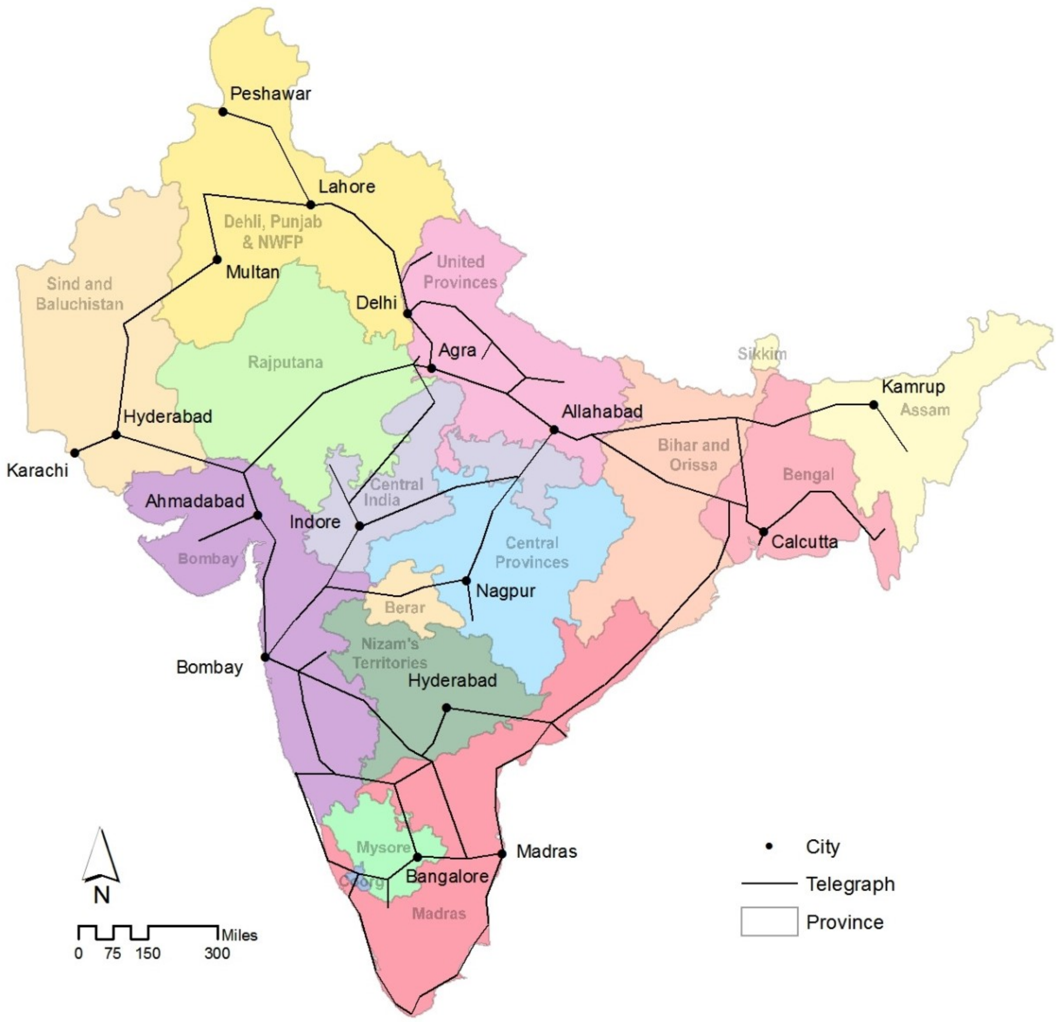


Figure 1B: Telegraph Network in 1872




Based on Map 8.1 in Wenzlhuemer (2013), p. 229.

Figure 2a: Railroad and Telegraph Penetration and Price Dispersion in Wheat Sample

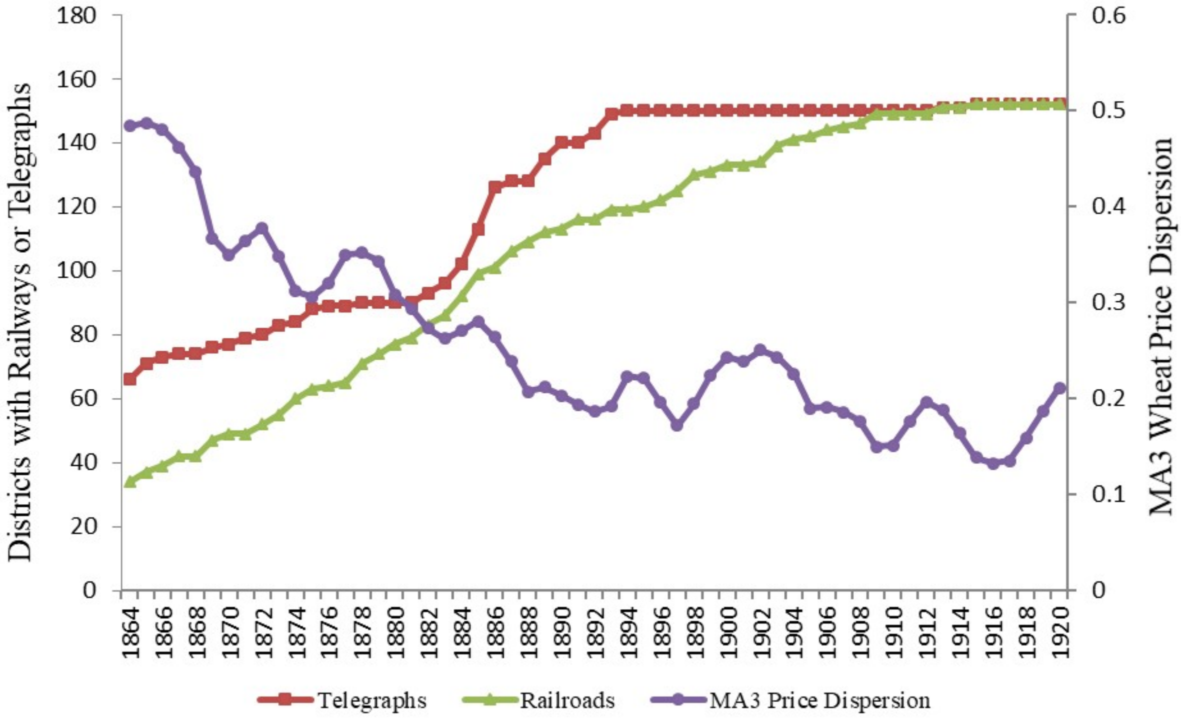



Figure 2b: Railroad and Telegraph Penetration and Price Dispersion in Rice Sample

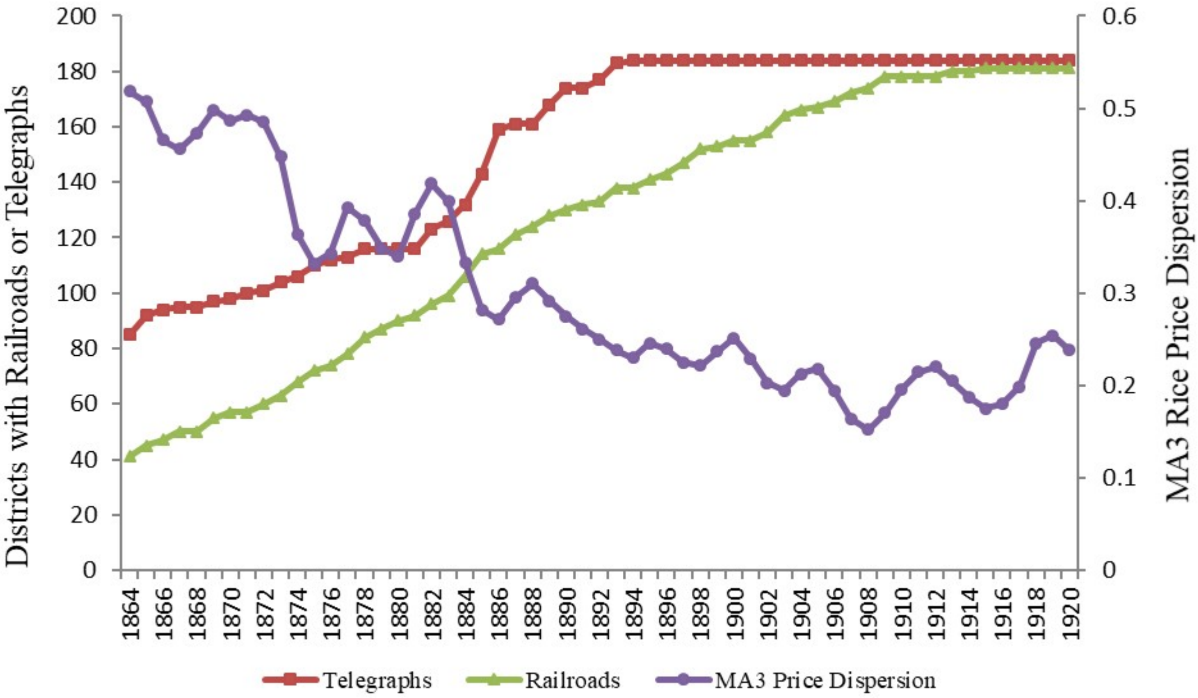


Figure 3a: Railroad and Telegraph Effects on Wheat Price Dispersion including Close Effects

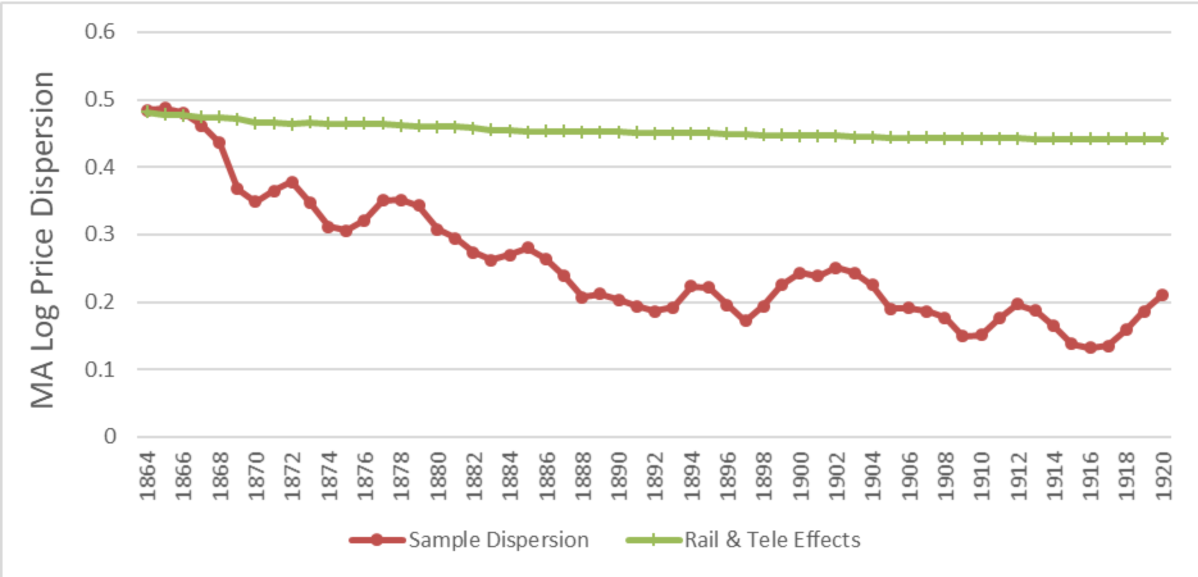
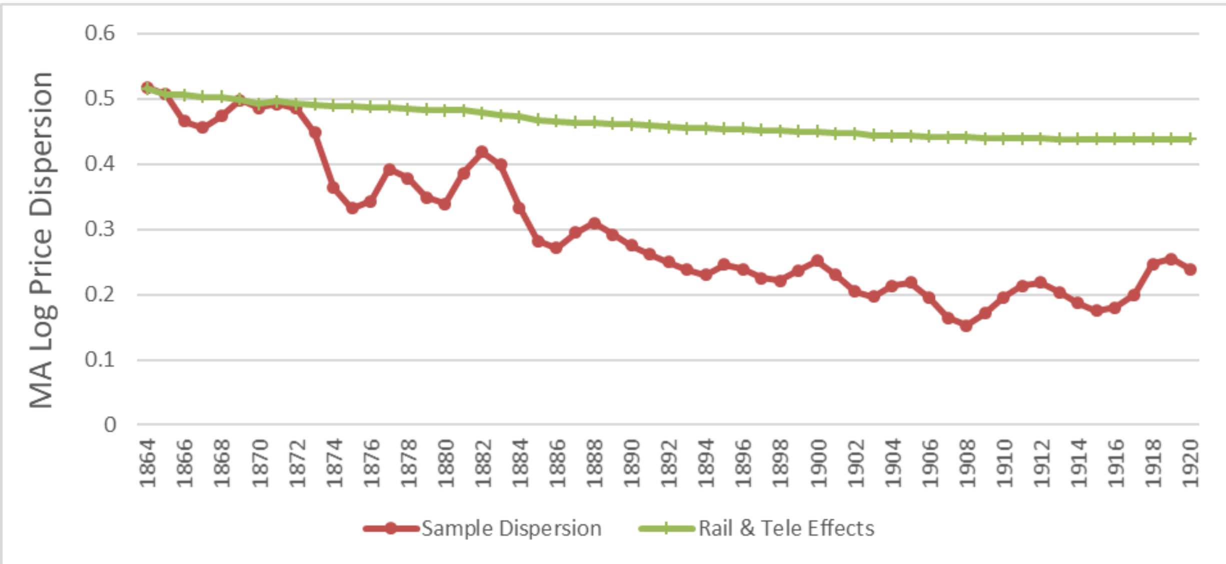



Figure 3b: Railroad and Telegraph Effects on Rice Price Dispersion including Close Effects




*Notes:* MA log price dispersion is the three-year moving average of the absolute value of the log price difference for each district pair. Rail and Tele Effects are relative to 1864 MA log price dispersion.

Table 1: Railway and Telegraph Line Mileage

Selected Years: 1854-1920

| | Railways | Telegraphs |
|---|---|---|
| 1854 | 35 | 91 |
| 1855 | 156 | 3,255 |
| 1860 | 734 | 10,436 |
| 1865 | 2,747 | 13,269 |
| 1870 | 4,775 | 14,275 |
| 1875 | 6,519 | 16,649 |
| 1881 | 9,892 | 20,346 |
| 1885 | 11,982 | 25,387 |
| 1890 | 16,404 | 35,279 |
| 1895 | 19,466 | 44,643 |
| 1900 | 24,752 | 52,909 |
| 1910 | 32,099 | 72,746 |
| 1920 | 36,735 | 88,417 |

Sources: *Statistical Abstracts Relating to British India*, 1865 to 1920.

Table 2: Summary Statistics: District Pairs

| | Wheat | | | Rice | | |
|---|---|---|---|---|---|---|
| | N | Mean | SD | N | Mean | SD |
| AbsDif | 650,161 | 0.257 | 0.239 | 980,192 | 0.293 | 0.262 |
| Rail | 650,161 | 0.502 | 0.500 | 980,192 | 0.460 | 0.498 |
| Tele | 650,161 | 0.664 | 0.472 | 980,192 | 0.700 | 0.458 |
| RailOnly | 650,161 | 0.038 | 0.191 | 980,192 | 0.033 | 0.179 |
| TeleOnly | 650,161 | 0.201 | 0.400 | 980,192 | 0.274 | 0.446 |
| RailAndTele | 650,161 | 0.464 | 0.499 | 980,192 | 0.427 | 0.495 |
| OneTeleOneRail | 650,161 | 0.022 | 0.148 | 980,192 | 0.028 | 0.164 |
| CloseRail | 650,161 | 0.167 | 0.373 | 980,192 | 0.127 | 0.333 |
| CloseTele | 650,161 | 0.246 | 0.431 | 980,192 | 0.218 | 0.413 |
| TelexGangesGT | 650,161 | 0.008 | 0.090 | 980,192 | 0.005 | 0.073 |
| TelexCoast | 650,161 | 0.001 | 0.030 | 980,192 | 0.014 | 0.119 |
| Dist | 650,151 | 575.6 | 307.0 | 980,192 | 698.2 | 376.7 |
| Income | 75,790 | 17.18 | 8.69 | 114,574 | 18.99 | 9.48 |

*Note:* See text for definitions.

Table 3: Baseline Regressions

| VARIABLES | (1)<br>Wheat<br>AbsDif | (2)<br>Wheat<br>AbsDif | (3)<br>Rice<br>AbsDif | (4)<br>Rice<br>AbsDif |
|---|---|---|---|---|
| Rail | -0.0323*** | | -0.0434*** | |
| | (0.0014) | | (0.0016) | |
| Tele | 0.0014 | | -0.0264*** | |
| | (0.0019) | | (0.0020) | |
| RailOnly | | -0.0569*** | | -0.0671*** |
| | | (0.0025) | | (0.0027) |
| TeleOnly | | -0.0065*** | | -0.0359*** |
| | | (0.0021) | | (0.0023) |
| RailAndTele | | -0.0334*** | | -0.0759*** |
| | | (0.0024) | | (0.0028) |
| OneTeleOneRail | | -0.0209*** | | -0.0375*** |
| | | (0.0036) | | (0.0033) |
| N | 650,161 | 650,161 | 980,192 | 980,192 |
| Adj R-sq | 0.507 | 0.507 | 0.484 | 0.485 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. *AbsDif* is the absolute value of the difference in log prices for each district pair. Rail implies the two district headquarters were connected by rail. *Tele* implies they were connected by telegraph. *RailOnly* implies they were connected by rail but not telegraph. *TeleOnly* implies the two headquarters were connected by telegraph but not rail. *RailAndTele* implies the headquarters were connected by both rail and telegraph, and *OneTeleOneRail* implies that one headquarters only had a railway and the other only had a telegraph.

Table 4: Robustness Tests: Wheat

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | With Income | Post-1871 | No Outliers | Thick Markets |
| VARIABLES | AbsDif | AbsDif | AbsDif | AbsDif |
| RailOnly | -0.0556*** | -0.0571*** | -0.0554*** | -0.0473*** |
| | (0.0057) | (0.0026) | (0.0025) | (0.0026) |
| TeleOnly | -0.0220*** | -0.0179*** | -0.0055** | -0.0081*** |
| | (0.0037) | (0.0021) | (0.0020) | (0.00212) |
| RailAndTele | -0.0451*** | -0.0416*** | -0.0325*** | -0.0359*** |
| | (0.0038) | (0.0024) | (0.0023) | (0.0025) |
| OneTeleOneRail | -0.0370*** | -0.0355*** | -0.0201*** | -0.0129*** |
| | (0.0112) | (0.0037) | (0.0035) | (0.0037) |
| Income | -0.0017*** | | | |
| | (0.0002) | | | |
| N | 75,790 | 555,464 | 649,160 | 600,481 |
| Adj R-sq | 0.576 | 0.519 | 0.502 | 0.501 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. *Income* is measured in millions of constant dollar rupees and is averaged over each district pair. Other variable definitions found in Table 3. No Outliers omits the 1,000 largest AbsDif observations. Thick Markets omits each district-pair with fewer than 40 observations.

Table 5: Robustness Tests: Rice

| VARIABLES | (1)<br>With Income<br>AbsDif | (2)<br>Post-1871<br>AbsDif | (3)<br>No Outliers<br>AbsDif | (4)<br>Thick Markets<br>AbsDif |
|---|---|---|---|---|
| RailOnly | -0.0494*** | -0.0763*** | -0.0650*** | -0.0781*** |
| | (0.0072) | (0.0027) | (0.0026) | (0.0029) |
| TeleOnly | -0.0380*** | -0.0470*** | -0.0336*** | -0.0350*** |
| | (0.0044) | (0.0022) | (0.0022) | (0.0023) |
| RailAndTele | -0.0240*** | -0.0872*** | -0.0723*** | -0.0751*** |
| | (0.0050) | (0.0027) | (0.0026) | (0.0028) |
| OneTeleOneRail | -0.0637*** | -0.0553*** | -0.0336*** | -0.0385*** |
| | (0.0107) | (0.0029) | (0.0031) | (0.0035) |
| Income | 0.00029* | | | |
| | (0.00015) | | | |
| N | 114,574 | 847,501 | 979,192 | 923,132 |
| Adj R-sq | 0.472 | 0.488 | 0.480 | 0.478 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. *Income* is measured in millions of constant dollar rupees and is averaged over each district pair. Other variable definitions found in Table 3. No Outliers omits the 1,000 largest AbsDif observations. Thick Markets omits district-pairs with fewer than 40 annual observations.

Table 6: Close Rail and Close Telegraph Variables

| VARIABLES | (1)<br>Wheat<br>AbsDif | (2)<br>Rice<br>AbsDif |
|---|---|---|
| RailOnly | -0.1180*** | -0.1620*** |
| | (0.0054) | (0.0056) |
| CloseRail | -0.0262*** | -0.0423*** |
| | (0.0024) | (0.0026) |
| TeleOnly | -0.0686*** | -0.1305*** |
| | (0.0053) | (0.0054) |
| CloseTele | -0.0540*** | -0.0872*** |
| | (0.0047) | (0.0051) |
| RailAndTele | -0.0944*** | -0.1729*** |
| | (0.0055) | (0.0057) |
| OneTeleOneRail | -0.0160*** | -0.0294*** |
| | (0.0036) | (0.0032) |
| N | 650,161 | 980,192 |
| Adj R-sq | 0.509 | 0.490 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. CloseRail implies that, among district headquarter pairs without a rail or telegraph connection, either both headquarters were close to a railway or one headquarters had a railway and the other was close to a railway. CloseTele is the telegraph analog to CloseRail.

Table 7: Interaction with Alternative Transport

| | (1) | (2) |
|---|---|---|
| | Wheat | Rice |
| VARIABLES | AbsDif | AbsDif |
| RailOnly | -0.1181*** | -0.1623*** |
| | (0.0054) | (0.0056) |
| CloseRail | -0.0264*** | -0.0430*** |
| | (0.0024) | (0.0026) |
| TeleOnly | -0.0677*** | -0.1313*** |
| | (0.0053) | (0.0054) |
| TelexGangesGT | -0.0242*** | -0.0177** |
| | (0.0040) | (0.0061) |
| TelexCoast | 0.0147 | 0.0278*** |
| | (0.0197) | (0.0084) |
| CloseTele | -0.0540*** | -0.0872*** |
| | (0.0047) | (0.0051) |
| RailAndTele | -0.0945*** | -0.1733*** |
| | (0.0055) | (0.0057) |
| OneTeleOneRail | -0.0160*** | -0.0293*** |
| | (0.0036) | (0.0032) |
| N | 650,161 | 980,192 |
| Adj R-sq | 0.510 | 0.490 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. *TelexGangesGT* is *TeleOnly* times a variable indicating if the two district headquarters were within 10 miles of the Ganges or 10 miles of the GT road. *TelexCoast* is *TeleOnly* times a variable indicating if the two district headquarters were within 10 miles of the coast.

Table 8: Interaction with Distance

| VARIABLES | (1)<br>Wheat<br>AbsDif | (2)<br>Rice<br>AbsDif |
|---|---|---|
| RailOnly | -0.1180*** | -0.1650*** |
| | (0.0054) | (0.0056) |
| CloseRail | -0.0270*** | -0.0454*** |
| | (0.0024) | (0.0027) |
| TeleOnly | -0.0828*** | -0.164*** |
| | (0.0057) | (0.0062) |
| DistxTeleOnly | 2.23e-05*** | 4.31e-05*** |
| | (4.16e-06) | (3.72e-06) |
| CloseTele | -0.0539*** | -0.0882*** |
| | (0.0048) | (0.0051) |
| RailAndTele | -0.0952*** | -0.176*** |
| | (0.0055) | (0.0057) |
| OneTeleOneRail | -0.0159*** | -0.0283*** |
| | (0.0036) | (0.0033) |
| N | 650,161 | 980,192 |
| Adj R-sq | 0.510 | 0.490 |

*Notes:* *** Significant at 1%, ** Significant at 5%, * Significant at 10%. Robust standard errors in parentheses, clustered at the district-pair level. District-pair and time fixed effects and constants not reported. *DistxTeleOnly* is distance between district headquarters times *TeleOnly*.

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