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Real Effects of Information Frictions: When the States and the Kingdom Became United†

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This paper exploits a unique historical experiment to estimate how information frictions distort international trade: the establishment of the transatlantic telegraph in 1866. I use newly collected data on cotton prices, trade, and information flows from historical newspapers and find that the average and volatility of the transatlantic price difference fell after the telegraph, while average trade flows increased and became more volatile. Using a trade model in which exporters use the latest news about a foreign market to forecast expected prices, I estimate the efficiency gains of the telegraph to be equivalent to 8 percent of export value. (*JEL* D83, F12, F14, L96, N71, N73)

Understanding the nature of the frictions that inhibit arbitrage across international goods markets and limit market integration is one of the central research objectives in international trade. Summarizing the literature, Anderson and van Wincoop (2004) and Head and Mayer (2013) observe that direct barriers to goods trade (e.g., transport costs and trade tariffs) have been found to be of minor importance, while more indirect barriers to trade and market integration (e.g., information frictions) have the potential to be of major importance, but are not yet well understood.

This paper focuses on information frictions as a potential explanation for "missing trade" (Trefler 1995) and low market integration (as measured by deviations from the law of one price (LOP), e.g., Rogoff, Froot, and Kim 2001) in goods trade. Information is essential for the efficient functioning of markets, but in reality is often limited or costly (Jensen 2007; Stigler 1961). For example, exporting firms have to spend considerable time and money to learn about preferences of consumers in foreign countries and often fail (Albornoz et al. 2012), especially if preferences change over time and production and export decisions must be made in advance (Hummels and Schaur 2010; Evans and Harrigan 2005; Collard-Wexler 2013). The

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distortions from information frictions are hard to measure, as information flows are usually unobserved and also notoriously responsive to the trading environment.

I use an historical experiment to circumvent these empirical pitfalls: the construction of the transatlantic telegraph connection in the nineteenth century, a large, exogenous reduction in information frictions. Before July 28, 1866, mail steamships took between 7 and 15 days to transmit information between the United States and Great Britain. The transatlantic cable reduced this information delay to a single day. The timing of the connection was exogenous and not anticipated, because ten years of technological setbacks obscured whether this new technology could ever succeed. This paper is, to my knowledge, the first in the trade literature to observe actual information flows, which are based on news about foreign prices reported in contemporary newspapers.[1] The information flows are used to measure the impact of information on prices and exports, and to derive microfoundations for exporters' behavior under information frictions.

This paper focuses on cotton, the most important traded good between Great Britain and the United States in the mid-nineteenth century. The dominance of "King Cotton" provides a unique setting in which to study information frictions, because newspapers published detailed and meticulous market reports on cotton. No other prices and exports were reported daily. Surprisingly, these rich data have never been systematically digitized. I use market reports from newspapers on both sides of the Atlantic to construct a daily dataset that includes cotton prices in New York and Liverpool, export flows and freight costs between the two ports, and detailed information flows for the period from one year before until one year after the telegraph connection. The use of this dataset has several advantages. First, using export as well as price data makes it possible to determine whether information has a real effect on trade, as opposed to only distributing profits across agents. Second, it makes it possible to study the impact of information frictions on a durable good. Jensen (2007) provides evidence that information reduces spoilage of fish, a highly perishable good, but it is not clear whether the same is true for a storable commodity. Third, shipping time makes imports predetermined, which allows me to identify the supply and demand functions required for the estimation of the efficiency gains brought by the telegraph.

Using these detailed data, I am able to document six reduced-form findings (described in the subsections of Section III): (A) The telegraph caused increased goods market integration, as the mean and volatility of the cross-Atlantic contemporaneous price differences fell. (B) Within the pre-telegraph period, faster steam-ships had a similar effect and increased market integration, whereas during the post-telegraph period, temporary technical failures of the transatlantic telegraph connection reduced market integration. (C) New York prices responded strongly to news from Liverpool, while Liverpool prices reacted less strongly to news from New York. (D) The telegraph reduced the mean and volatility of the difference between the current price in New York and the latest known price in Liverpool. This

[1] Previous papers using exogenous variation in information frictions used the presence of mobile phone coverage (Jensen 2007; Aker 2010), internet kiosks (Goyal 2010), or even the transatlantic telegraph connection (Ejrnæs and Persson 2010), but none of these papers observed information flows directly. Observing information ("news") and relating it to prices is much more common in the finance literature (for example, Cutler, Poterba, and Summers 1989; Koudijs 2015, 2016).

last finding is a new contribution to the literature on the impact of the telegraph and information frictions on financial markets (e.g., Garbade and Silber 1978; Hoag 2006) and shows that market participants did not naïvely arbitrage away the price difference between the current price in New York and their latest known Liverpool price, but instead took into account how outdated this information was when forming expectations about future prices. (E) Information frictions had real effects on trade flows and were not just a reallocation of profits across market participants, because exports responded to news about Liverpool prices. To my knowledge, this paper provides the first evidence that the telegraph had real effects on exports. (F) After the telegraph, exports were on average both higher and more volatile.

To establish a causal relationship between these findings and the telegraph, I use three complementary strategies. First, I show that the findings are robust to a number of alternative explanations (e.g., transport cost variations, supply irregularities in the aftermath of the American Civil War, fluctuations within commodity points in no-trade periods, change in the market structure of merchants, futures trading, and anticipation effects). Second, to rule out any confounding trends, I use another source of exogenous variation in information flows before the telegraph: the irregular passage times of steam-ships across the Atlantic, which were driven by weather conditions. Third, I link prices and exports to information flows and show that outcomes respond to actual rather than counterfactual information, providing direct evidence of the underlying mechanism.

I present a partial equilibrium model of trade under information frictions that provides a microfoundation for the empirical findings and can be used to measure the efficiency gain of reducing information frictions. In the model, as in nineteenth century trade, intermediaries act as arbitrageurs across geographic markets. They buy cotton from suppliers at a centralized exchange in New York and ship it to Liverpool, where they sell it to cotton millers, again at a centralized market place. Aggregate demand from cotton millers follows a stochastic, autocorrelated process. Shipping takes time, so merchants have to make their export decision before they know the realization of the demand shock, and will base it on the prices they *expect* to generate in Liverpool. Frictions affect the information available to merchants when they construct these conditional expectations: if frictions are low, current market conditions in Liverpool are considered. If frictions are high, lagged information about Liverpool market conditions must be used to predict future selling prices. In this model, merchants maximize expected profits, *conditional* on their information set.[2]

In the model I study the implications of storability for the operation of markets with information frictions. Storage moderates the impact of information frictions but it cannot eliminate them. The model shows why. For example, consider a positive demand shock in Liverpool. In this case it is not optimal to release enough stock to fully eliminate the effect of the demand shock, because prices in Liverpool need to increase to incentivize additional exports to replenish stock for the next period. But if prices in Liverpool go up, it is not optimal to release the stock from storage in the current period. In equilibrium it is optimal to distribute the effect of a demand

[2] This is different from Allen (2014), who models information frictions as a costly search across markets, and merchants optimally decide on how much information to acquire.

shock over time by gradually increasing exports, so replenishment of stock takes longer than shipping time.

I calibrate the model to match the historical data before the telegraph was introduced. Then I conduct a counterfactual analysis by decreasing information frictions to simulate the effect of the telegraph. The resulting predictions are consistent with the reduced-form evidence: the volatility of trade flows increases after the telegraph connection, because exports follow expected demand shocks in Liverpool. With better information, expected demand shocks become more volatile. To see this, consider two extremes: without any information, expected demand is equal to a constant, the unconditional mean, which has zero variance. With perfect foresight, expected demand is actual demand and has the variance of the demand shock. In between, more information increases the variance of expected demand, as expected demand follows actual demand more closely.

Average exports are lower before the telegraph connection, because periods of high demand are systematically underestimated with information frictions. This asymmetry arises from restricting exports to be nonnegative: while periods of low demand are also systematically overestimated with information frictions, in these periods it is never profitable to export. As a result, average exports increase after the telegraph, because in periods of high demand exports are higher. The distorted export flows are reflected in the difference in prices across the Atlantic: after the telegraph, the average and the volatility of the cross-Atlantic price difference decrease.

The model provides an analytical solution for the lower bound of the deadweight loss arising from distorted trade flows under information frictions based on Harberger Triangles: the deadweight loss from information frictions is a function of the squared observed price difference between New York and Liverpool (taking into account the shipping lag) as well as the slopes of the demand and supply curves. The reduction in the absolute observed price difference after the construction of the telegraph connection corresponds to the abolishment of an ad valorem tariff of around 7 percent. To measure how this translates into efficiency gains, the slopes of the supply and demand functions need to be estimated. This estimation is usually difficult due to the simultaneous determination of quantity and prices, and a valid instrument cannot always be found. I propose a novel identification strategy that exploits the fact that exports are predetermined once they arrive in Liverpool, since shipping in transatlantic cotton trade takes time. This breaks the simultaneity problem under the assumption of i.i.d. demand shocks. For the case of autocorrelated demand shocks, I split the unobserved demand shock into what is known at the time of exporting and demand innovations while the good is being shipped. The former can be controlled for using the lagged demand function, while the latter are exogenous to exports.

Combining the estimated parameters with the observed price differences, I estimate the efficiency gain from the telegraph to be 8 percent of the annual export value of American cotton. About three-quarters of this gain comes from the reduced variance of the cross-Atlantic price difference as cotton is allocated more efficiently across days and weeks within a year, while the rest is due to increased average trade.

What are the implications of this paper for today's modern world, whose optical glass fiber cables have long since replaced the copper wires of the telegraph? The historical example of the transatlantic telegraph provides a microfoundation for how exporters (or equivalently, producers) use information about demand shocks to forecast demand and decide ex ante on export (or production) quantities. Exporters and firms still face this problem today, and emerging technologies such as the real-time analysis of "big data" have the potential to help firms forecast demand (McAfee and Brynjolfsson 2012). My model can be used to assess the efficiency gains in such a setting. The model also illustrates that technologies which reduce the time lag between the production decision and consumption, such as faster transport and better supply chain management, are complementary to information technologies that improve the precision of forecasting consumer demand (see also Hummels and Schaur 2010, 2013; Evans and Harrigan 2005; Aizenman 2004; Harrigan 2010). In fact, firms that successfully manage their supply chain focus on both of these dimensions (e.g., Ferdows, Lewis, and Machuca 2004 describes Spanish textile manufacturer Zara).

This paper contributes to an emerging literature on information frictions in goods trade. On one hand, a number of empirical papers have documented the impact of information on market integration. For example, access to mobile phones (Jensen 2007; Aker 2010; Allen 2014), internet kiosks (Goyal 2010), and internet comparison-shopping sites (Brown and Goolsbee 2002) have been found to reduce average price dispersion across goods markets. Most closely related to this paper is an earlier study by Ejrnæs and Persson (2010) which estimates faster shock transmission after the telegraph using weekly wheat prices. However, since their price series exhibits a gap of 15 years around the time of the establishment of the telegraph connection, it is difficult to distinguish the effect of the telegraph from other confounding trends during that period.

On the other hand, an increase in the number of immigrants (interpreted as giving access to networks, see Rauch and Trindade 2002; Head and Ries 1998; Rauch 1999, 2001) or web hosts in a country (Freund and Weinhold 2004) and a decrease in international telephone call rates (Portes and Rey 2005; Fink, Mattoo and Neagu 2005) have been found to increase trade. In contrast, I observe actual information flows, which allows me to pin down the mechanism by which information affects trade. Relating actual information ("news") to prices is much more common in the finance literature (e.g., Cutler, Poterba, and Summers 1989; Koudijs 2015, 2016), where the transatlantic telegraph has been shown to reduce price dispersion of financial securities (Garbade and Silber 1978; Hoag 2006). Building on this literature, I show that information is important for the real economy and not just financial markets: information affects prices in goods markets (which is much less obvious, as physical goods need to be shipped across the Atlantic in order to equalize prices) and the flow of real physical goods across countries.

The trade literature suggests several mechanisms through which information can affect trade. Freund and Weinhold (2004) argue that communication and information reduce the fixed cost of market access, while Fink, Mattoo, and Neagu (2005) interpret communication cost as variable trade cost. Alternatively, some authors interpret information as reducing search frictions, e.g., sellers are able to sell their goods at the market with the highest demand (e.g., Jensen 2007) and buyers find the seller with the best offer (e.g., Brown and Goolsbee 2002). Allen (2014) and Dasgupta and Mondria (2016) model information cost as search cost and allow agents to endogenously determine their information set. These models can rationalize the fact that countries import and export the same good at the same time.

In the current model, there is no search across markets (because there are only two countries) nor across buyers and sellers within a country (because there are centralized markets in each country). Also, information is exogenously determined and not optimally chosen by each agent. Instead, this paper focuses on using exogenous information to improve the forecast of a stochastic demand shock. Closest in spirit is a recent model by Baley, Veldkamp, and Waugh (2016), which introduces uncertainty about endowments in a two-country trade model.

Most of the literature mentioned has focused on the impact of information on average price differences and average trade. Instead, this paper points out that the variance of both trade and the price difference can be much more strongly affected by information frictions than the means. This is important, because the variance of the price difference has a direct first-order impact on deadweight losses; ignoring this underestimates the efficiency effect of information.

My paper focuses exclusively on the information effects of the telegraph. However, there might be other, long-term effects. For example, Lew and Cater (2006) argue that the telegraph reduced transport costs by increasing the capacity utilization of shipping, which increased trade flows (however, based only on data after 1870). Clark and Feenstra (2003) argue that the telegraph enabled international transfer of other production technologies. Ellison (1886) claims that the transatlantic cable subsequently led to the development of cotton futures trading in the 1870s, because cotton could be sold while in transit. These and other additional long-term effects would increase the efficiency gains brought about by the telegraph beyond the ones estimated in this paper.

The structure of the paper is as follows. Section I describes the historical setting, Section II describes the collected dataset, and Section III provides reduced-form evidence on the effect of the telegraph. Section IV develops a theoretical model of information frictions and intermediaries in international trade consistent with the empirical findings. Section V estimates the efficiency gains from reducing information frictions, and Section VI offers conclusions.

I. Historical Setting

Transatlantic cotton trade was the world's most important trade linkage in the mid-nineteenth century.[3] Cotton accounted for more than one-half of US exports (Bruchey 1967) and one-third of Great Britain's imports (*The Economist* 1866). The reasons behind this importance were the superior quality of American cotton on one hand and the technological dominance of the British textile industry on the other. Virtually all the cotton destined for Great Britain arrived at Liverpool, while New York was the major exporting port, responsible for one-third of total US cotton exports (followed by New Orleans and Mobile). British cotton spinners needed slightly different equipment to spin American versus other cotton (see also Hanlon 2015), and therefore could substitute only imperfectly across cotton from different countries in the short run (Farnie 1979).

[3] In this section I provide a short overview of the historical setting. For more details, please refer to the online Appendix.

Merchants bought cotton at the New York exchange from cotton farmers (alternatively, they could sell it to the domestic cotton-spinning industry), shipped it to Liverpool, and sold it at the Liverpool exchange to cotton millers. The merchant community was thriving and competitive. When merchants bought their cotton at the New York exchange, they had to forecast demand conditions in Liverpool upon its arrival. Demand at the Liverpool exchange originated from cotton millers, whose customers were both domestic and foreign; mainly from Continental Europe. Export demand for cotton textiles fluctuated frequently depending on the course of wars and peace negotiations on the continent, which could take quick and unexpected turns.

Information was therefore important at the cotton exchanges. Each exchange had a newsroom, which provided newspapers, circulars, and some telegraphic information to individual merchants at no cost (Farnie 2004). Most important for the purposes of this paper, it provided the *Reuter's Telegram*, a compilation of news that included cotton prices. These cotton prices can therefore be interpreted as public information from the point of view of merchants.

Before the transatlantic telegraph connection, commercial information such as cotton prices was transmitted using a combination of existing land-based telegraph cables and steam-ships. Steam-ships usually took around ten days to cross the Atlantic, but depending on weather this could be anything between one and three weeks. The transatlantic connection immediately changed communication flows dramatically. Communication was now possible with only a one-day delay (messages from Great Britain to New York still had to be retransmitted at each of several intermediate posts (Lew and Cater 2006)). Occasional technical breakdowns were usually repaired within a couple of days.

The timing of the successful telegraph connection was unforeseen and exogenous to economic conditions, characterized by a series of failures and setbacks. It took five attempts over the course of almost ten years until a lasting connection was established. The first attempt in 1857 resulted in a snapped cable, whose ends were lost in the deep sea. The second attempt in 1858 produced a working connection, but too slow for commercial purposes, and the connection lasted only three weeks. The media even began to suspect that the working connection had been a "hoax" altogether. The *Boston Courier* asked: "Was the Atlantic Cable a Humbug?" The fourth attempt in 1865 also ended in a broken cable. By 1866 there was little confidence left, but even if the public had expected this fifth attempt to work, the precise timing could not have been foreseen, as weather conditions determined the progress of the cable-laying steam-ship.

Nonetheless, to universal surprise and excitement, on July 28, 1866 the first telegraph message, a congratulatory message from the Queen of England to the President of the United States, was transmitted. Among the next messages were already the most important commercial news, which included cotton price quotations. From then on, the telegraph worked surprisingly quickly and reliably.

Once completed, the transatlantic telegraph raised high hopes among contemporary press: "The Atlantic Cable will tend to equalize prices and will eliminate from the transactions in bonds, in merchandise and in commodities, an element of uncertainty which has had the effect of […] seriously damaging the commercial relations between this country and Europe."[4] This paper uses empirical and theoretical evidence to assess whether this prediction came true.

II. Data Description

To establish a causal relationship between delayed information, market integration, and trade flows, data requirements are substantial. First, I need *wholesale* price and export data on an *identical* good from at least two different marketplaces. Second, these prices and export flows should be reported daily to correspond to the actual adjustment horizon of prices to information in the real world (Ejrnæs, Persson, and Rich 2008). I can then relate price changes to news arriving that same day. Third, I need data on information flows across the Atlantic.

The importance of cotton in the mid-nineteenth century allowed me to locate newspapers at the most important ports on either side of the Atlantic (the *New York Times* and the *Liverpool Mercury*) that provided detailed, daily information on cotton markets and trade flows. Furthermore, these newspapers also reported news about foreign cotton prices, which makes it possible to reconstruct information flows. In fact, the richness of cotton data is extraordinary; no other good is consistently reported with such high frequency in two different countries for the same variety around 1866.[5] Importantly, prices are reported for the same quality of cotton: "middling American," where middling indicates a specific quality of American cotton (out of seven different, narrowly defined quality categories). The New York and Liverpool exchanges used the same quality classification scheme, ensuring that the qualities are comparable.

The resulting dataset combines four types of data: market information about the Liverpool exchange, market information about the New York exchange, trade flows between New York and Liverpool, and information flows from New York to Liverpool (and vice versa).[6] *The New York Times* also reported a weekly and later biweekly estimate of the stock of cotton in the warehouses, as well as the daily "cotton receipts," i.e., the cotton that arrived at the exchange from the hinterland and Southern ports on any given day. I convert the prices at the New York exchange from US dollars to pounds sterling using daily exchange rates from the historical time series provided by *Global Financial Data*. Note that exchange rate fluctuations were very small compared to price fluctuations, and do not drive the results. A figure of the resulting time series of prices is provided in the online Appendix. *The New York Times* also had a separate "Freights" section, which reported daily the bales of cotton that were shipped to Liverpool, as well as the freight cost paid for that shipment.

I can reconstruct the data on information flows, as both newspapers reported the latest mail ship and telegraph arrivals on any given day and its commercial information. The newspapers also reported the origination date of these business indicators in the other market and the arrival date of the information. The difference in these

[4] *New York Evening Post*, July 30, 1866, as cited in Garbade and Silber (1978, p. 827).

[5] Ejrnæs, Persson, and Rich (2008) document a general price convergence in weekly wheat prices over the course of the nineteenth century, but do not attribute it to specific sources such as the transatlantic telegraph. Since wheat trade stops for several years around the time of the telegraph, it is difficult to establish a causal relationship between the telegraph and market integration using wheat prices.

[6] More detailed information about the data collection is provided in the online Appendix.

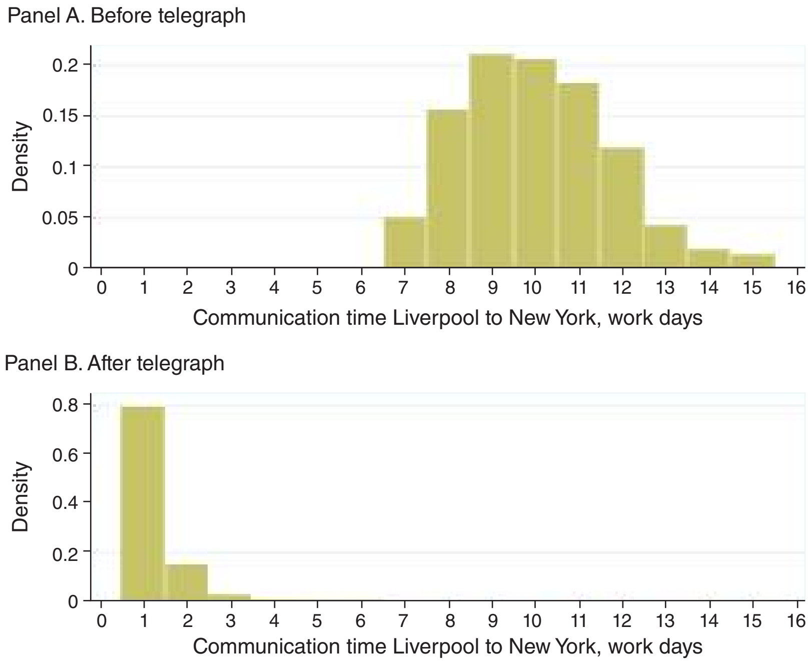

Figure 1. Distribution of Information Lags between New York and Liverpool

dates yields the information transmission time across the Atlantic for any given day, which I call "information delay l" (see online Appendix for a figure).

My final database comprises 604 observations, one for every work day between July 29, 1865 and July 27, 1867. The American Civil War between April 1861 and April 1865 severely disrupted cotton exports from the United States, restricting the period of analysis. Before the Civil War, newspapers did not report daily cotton prices. While it is possible to extend the period of analysis to years after 1867, I kept symmetry between the before- and after-telegraph periods.

III. Reduced-Form Findings

As stated above, the telegraph changed information frictions suddenly and dramatically. Figure 1 shows the distribution of information lags before and after the telegraph. Table 1 provides summary statistics and confirms that the drop in average information transmission speed after the establishment of the telegraph connection was statistically significant.

How did this drop in information frictions affect the integration of the Liverpool and New York cotton markets? In this section I develop six reduced-form findings that describe what happened to cotton prices and trade. These findings summarize the three complementary strategies I use to establish a causal effect of the telegraph. First, I perform a number of robustness checks on before/after telegraph comparisons. Second, to rule out any confounding trends, I use another source of exogenous variation in information flows *within* the period before the telegraph was established, i.e., the irregular passage times of steam-ships across the Atlantic driven by weather conditions. Third, I link prices and exports directly to information flows

Table 1—Summary Statistics

	Before telegraph	After telegraph	Difference
Information lag l_t	10.03	1.31	−8.72
	(0.13)	(0.06)	(0.15)
Liverpool price, p_t^{LIV}	18.11	13.16	−4.95
	(0.33)	(0.15)	(0.36)
New York price, p_t^{NY}	15.55	11.51	−4.04
	(0.21)	(0.13)	(0.25)
Price difference, $p_t^{LIV} - p_t^{NY}$	2.56	1.65	−0.91
	(0.18)	(0.05)	(0.19)
Exports	459.88	631.80	171.90
	(37.64)	(61.80)	(72.37)

Notes: Information lag l_t measures how many days it takes to communicate between Liverpool and New York. Prices are in pence per pound of cotton (using the daily exchange rate as described in the text and the online Appendix). The price difference is the difference between the price in Liverpool and in New York on the same day. Exports from New York to Liverpool are given in bales. Newey-West standard errors (lag = 2) in parentheses.

and show that outcomes respond to actual rather than counterfactual information, providing direct evidence on the underlying information mechanism.

A. The Telegraph Caused Increased Goods Market Integration, as the Mean and Volatility of the Contemporaneous Price Differences Fell

The degree of market integration is usually measured by the contemporaneous price difference between two markets (following the literature on the LOP, e.g., Dybvig and Ross 1987; Froot and Rogoff 1995, and the literature on the impact of information frictions on financial markets, e.g., Garbade and Silber 1978). This price difference captures any barrier to price arbitrage across markets (conditional on positive trade flows), such as transport and other transaction costs, including information frictions. If the telegraph reduced information frictions, we should expect to see a decrease in the contemporaneous price difference.

Figure 2 plots the contemporaneous difference between Liverpool and New York cotton prices, $p_t^{LIV} - p_t^{NY}$. The vertical line indicates July 28, 1866, the date when the telegraph connection was established. The change in the behavior of the price difference thereafter is striking: the volatility of the price difference falls sharply, and there are fewer very large or very small values. The average price difference falls as well. Table 1 shows that the average price difference was 2.56 pence/pound in the pre-telegraph period (16 percent of the New York price) and fell to 1.65 pence/pound. This reduction is statistically significant and corresponds to a fall of 35 percent. The variance of the price difference falls by even more, by 93 percent.[7]

Are these drops causally related to the transatlantic telegraph? The troublesome history of that connection is in favor of this interpretation: the timing of its success was driven by technical "luck" and the weather affecting the advancement of the cable-laying steam-ship and its ability to locate and repair breaks. The date of the

[7] The variance of the price difference normalized by the respective means falls by a similar percentage. A corresponding figure with log prices is provided in the online Appendix and is very similar.

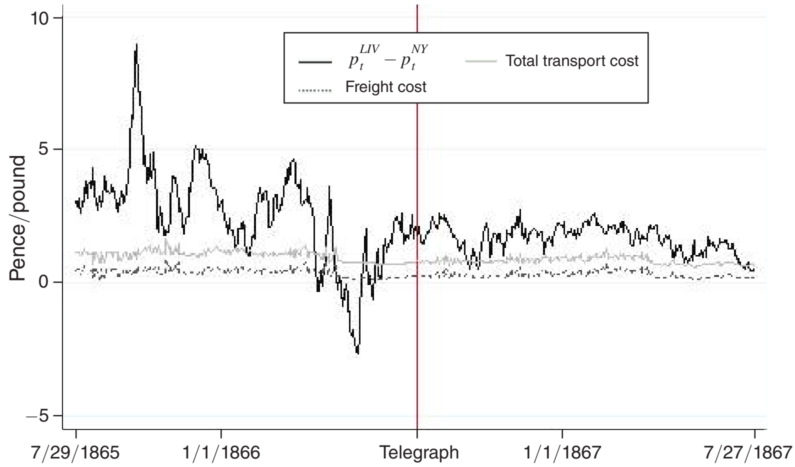

Figure 2. Differences between Liverpool and New York Cotton Prices, Freight Cost, and Transport Cost

connection could not have been deliberately timed by market participants to coincide with other market events or developments, and anticipation effects can also safely be excluded. However, due to the detailed nature of my data, I can go even further and control for alternative explanations in Table 2. Column 1 shows the baseline drop in the contemporaneous price difference after the telegraph.

Column 2 makes several adjustments. First, I subtract daily freight cost and other transport costs from the dependent variable. Detailed daily transport costs are rarely available in empirical papers, but I was able to obtain daily freight cost of cotton for shipment from New York to Liverpool from the *New York Times*, and all other transport cost components (e.g., bagging, marking, wharfage, cartage, dock dues, weighing, storage at the port, fire and marine insurance, Liverpool town dues, brokerage) from contemporary bookkeeping figures of merchants (more details are provided in the online Appendix; Figure 2 plots the freight rates and total transport cost).[8]

Second, price differences reflect the barriers to arbitrage only when there is trade between the two markets.[9] I therefore reduce the sample to exclude a period of about four weeks during May 1866 (before the telegraph), when the threat of a war between Austria and Prussia depressed demand for cotton in Liverpool and lowered prices so much that exporting became unprofitable.

Third, I control for disruptions in cotton trade that were caused by the American Civil War, which ended just three months before my sample period. Cotton production fell by three-quarters (from four to one million bales) during the Civil War, and

[8] Note that 83.1 percent of transport costs are charged based on weight. This large share of unit transport cost is also why my preferred specification to test the LOP is in levels rather than logs; the log transformation would be helpful only with ad valorem transport costs. Nonetheless, the results are robust to using log prices; the regression results in log prices are provided in the online Appendix.

[9] During no-trade periods, the price difference fluctuates freely between the bounds given by the transport costs (called commodity points): $-\tau_t < p_t^{LIV} - p_t^{NY} < \tau_t$ and is not informative about trade barriers. Notice that regression results using the absolute price difference $\left|p_t^{LIV} - p_t^{NY}\right| - \tau_t$ as a dependent variable are very similar. However, since there are no exports from Liverpool to New York during the whole sample period, this is not the correct relationship to test.

Table 2—Effect of Telegraph on Average and Variance of Contemporaneous Cotton Price Difference between Liverpool and New York

	$p_t^{LIV} - p_t^{NY}$ (1)	$p_t^{LIV} - p_t^{NY} - \tau_t$ (2)	$p_{t+k}^{LIV} - p_t^{NY} - \tau_t$ (3)	$\widehat{\text{var}}$ of $p_t^{LIV} - p_t^{NY}$ (4)	$\widehat{\text{var}}$ of $p_t^{LIV} - p_t^{NY} - \tau_t$ (5)	$\widehat{\text{var}}$ of $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$ (6)
Constant	2.56	1.45	1.34	3.36	2.15	3.88
	(0.18)	(0.16)	(0.21)	(0.59)	(0.40)	(0.77)
Telegraph dummy	−0.91	−0.91	−0.87	−3.11	−1.97	−3.80
	(0.19)	(0.15)	(0.21)	(0.59)	(0.43)	(0.86)
Cotton supply$_{t-1}$		0.13	0.10		0.01	0.12
		(0.03)	(0.04)		(0.08)	(0.13)
Exclude no-trade periods		Yes	Yes		Yes	Yes
Observations	604	575	575	604	575	575

Notes: For more details on specifications and specifications adding one robustness check at a time, see the online Appendix. Columns 2 to 3 and 5 to 6 exclude the period of around four weeks during May 1866, when exporters were inactive because the price in New York exceeded the price in Liverpool; and subtract transport cost which include freight cost and other transport cost. Columns 3 and 6 use the price in Liverpool at the time of the arrival of the shipment to adjust for the transport time of shipment (k is equal to the steamship travel time, which was used to transport the samples of cotton bales that could be used for transactions on the exchange). Columns 4 to 6 use an estimator of the variance of the price difference as a dependent variable: $\widehat{\text{var}}(pdiff_t) := \frac{N_{before}}{N_{before}-1}(pdfiff_t - \overline{pdiff}_{before})^2$ if the observation is before the telegraph, and $\widehat{\text{var}}(pdiff_t) := \frac{N_{after}}{N_{after}-1}(pdiff_t - \overline{pdiff}_{after})^2$ if the observation is after the telegraph. This implies that the coefficient on the constant yields the sample variance on the period before the telegraph, and the coefficient on the telegraph dummy yields the change in the sample variance before versus after the telegraph. Newey-West standard errors in parentheses (lag = 2).

did not again reach prewar levels until 1870 (see the online Appendix for a figure). During both harvest years immediately after the Civil War, from which the data in my sample covering the time around the telegraph are taken, cotton production was around one-half of prewar levels. It is reassuring that total annual cotton production is similar in those two years. However, it is possible that cotton supply is still disrupted during the first year of my data, which is also the first year after the Civil War. If there are no barriers to arbitrage, a larger volatility of production affects only price levels and not price difference, as shocks are transmitted to the other country. To account for the possibility that there were some barriers to arbitrage, and to investigate whether supply irregularities therefore had an effect on the price difference, I use data on cotton receipts, which measure the supply of cotton at the New York exchange from farms on any given day, and control for the one-day lagged cotton supply in the regression.[10]

Column 2 in Table 2 makes all these adjustments, but the results are basically unchanged.[11]

While the contemporaneous price difference is a widely used and useful proxy to measure market integration, it takes time to ship goods across the Atlantic, and merchants should have used the price in Liverpool at the time of the arrival of the shipment of their cargo p_{t+k}^{LIV} as basis for arbitrage (or rather, their expectation of

[10] One-day lagged rather than contemporaneous cotton supply is used because handling and turn-around of cotton takes a day. I thank an anonymous referee for pointing this out. More details are provided in the online Appendix.

[11] In the online Appendix, I provide regression results which implement each of the mentioned adjustments at a time.

that price). In order to see whether the time delay due to shipping confounds the estimation, I use the dependent variable $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$ in column 3 of Table 2, but the effect of the telegraph is also visible in this specification.

In columns 4 to 6, I conduct the same robustness checks for the variance in price difference. I use the following estimator of the daily variance of the price difference in the dependent variable: $\widehat{\text{var}}(pdiff_t) := \frac{N_{before}}{N_{before}-1}\left(pdiff_t - \overline{pdiff}_{before}\right)^2$ if the observation is from the year before the telegraph, and $\widehat{\text{var}}(pdiff_t) := \frac{N_{after}}{N_{after}-1}\left(pdiff_t - \overline{pdiff}_{after}\right)^2$ if the observation is from the year after the telegraph. Even though this estimator is based on only a single observation (the price difference on that day t, in addition to the mean before or after the telegraph), it is an unbiased estimator of the variance, which is all that is needed for a consistent regression coefficient (though it may not be the most efficient method of estimation). I regress this squared deviation of the price difference from the mean as a dependent variable and regress it on a dummy that indicates the period after the telegraph.[12] The coefficient on the telegraph dummy then corresponds to the change in variance. Column 4 shows that the variance of the price difference falls precipitously after the telegraph; the drop is around 90 percent. Column 5 shows that excluding no-trade periods explains one-third of the drop, but controlling for shipping time adjustments in column 6 further increased the effect of the telegraph on the variance of the price difference.

Contemporary accounts observe that the transatlantic telegraph contributed to the development of futures trading in cotton across the Atlantic, as for the first time information traveled faster than goods (Dumbell 1927; Irwin 1954; Ellison 1886). If the change in the pattern of the price difference is due to the introduction of futures trading, it is indirectly caused by the telegraph (rather than directly by changing information frictions). However, the development of futures trading was not immediate; the "invention" of transatlantic futures trading (including short selling and hedging) is usually dated to 1868 or 1869 (Woodman 1968) and did not take off fully only until organized futures trading at the exchanges was developed in the 1870s. Since this is after my sample period, the introduction of futures cannot explain my findings.

Finally, it is interesting to explore whether the observed change in the price difference is the result of a change in markups by merchants, perhaps because of increased competition. I used data on individual shipments from the Bills of Trade to compute Herfindahl indices for cotton merchants separately for shipments from the United States and shipments from Egypt and the East Indies (see the online Appendix). The Herfindahl index was very low, around 0.05, suggesting high competition, and this did not change after the telegraph, either for merchants to the United States or to the East. Therefore it does not seem plausible that a change in markups could be responsible for the findings.

[12] As an alternative measure, in the online Appendix I normalize the dependent variable by the average price difference before and after the telegraph connection (similar to a coefficient of variation).

Table 3—Effect of Daily Information Lag on the Variance in Cotton Price Difference

Dependent variable:	$\ln \widehat{\text{var}}\left(p_t^{LIV} - p_t^{NY} - \tau_t\right)$		
	(1)	(2)	(3)
Telegraph dummy	−2.10		−0.78
	(0.28)		(0.83)
Information lag l_t, work days		0.23	0.15
		(0.03)	(0.09)
ln(cotton supply$_{t-1}$)	−0.16	−0.16	−0.16
	(0.10)	(0.10)	(0.10)
Observations	574	574	574

Notes: $\widehat{\text{var}}(pdiff_t) := \frac{N_{before}}{N_{before}-1}(pdiff_t - \overline{pdiff}_{before})^2$ if the observation is before the telegraph, and $\widehat{\text{var}}(pdiff_t) := \frac{N_{after}}{N_{after}-1}(pdiff_t - \overline{pdiff}_{after})^2$ if the observation is after the telegraph. This implies that the coefficient on the constant yields the sample variance on the period before the telegraph, and the coefficient on the telegraph dummy yields the change in the sample variance before versus after the telegraph. No-trade periods are excluded as in Table 2. Newey-West standard errors (lag = 2) in parentheses.

B. Faster Steam-Ships Had an Effect Similar to That of the Telegraph in the Pre-Telegraph Period. They Also Increased Market Integration. Similarly, in the Post-Telegraph Period, Temporary Technical Failures of the Transatlantic Telegraph Connection Reduced Market Integration

The previous analysis compares the variance of the price difference in the year after the telegraph to the variance in the previous year based on a one-time change in information frictions. However, even before the telegraph connection, the information delay was not constant: in the pre-telegraph period, weather and wind accelerated or delayed mail steam-ships. Similarly, even after the telegraph cable was in place, occasional technical breakdowns stopped communication temporarily. These weather-related and technical variations in information lag can be used as additional, exogenous "mini-experiments" to test whether the large changes in the variance of the price difference hold when using smaller daily shocks to information delays.

This is tested in Table 3. As a starting point, column 1 regresses the daily estimate of the variance of the price difference on the telegraph dummy, confirming that after the telegraph, the variance of the price difference fell. Column 2 uses instead the *daily* information lag as a regressor, i.e., how old the most recent information from the other side of the Atlantic was on a given day in the sample (graphed in the online Appendix). The coefficient is positive and significant, confirming that older information (i.e., longer information lags) increased the variance in the price difference. For each additional day information takes to get from Liverpool to New York, the deviation from the LOP increases by 23 percent. Column 3 uses both the telegraph dummy and the information lag as regressors and is the most demanding test: the positive coefficient in the information lag shows that even *within* either the pre- and post-telegraph years, older information increased the variance of the price difference.

Overall, more recent information leads to the same reduction in the variance of the price difference, no matter whether the source of this reduction is the telegraph, faster steam-ships bringing information (in the pre-telegraph period), or telegraph repairs (in the post-telegraph period).

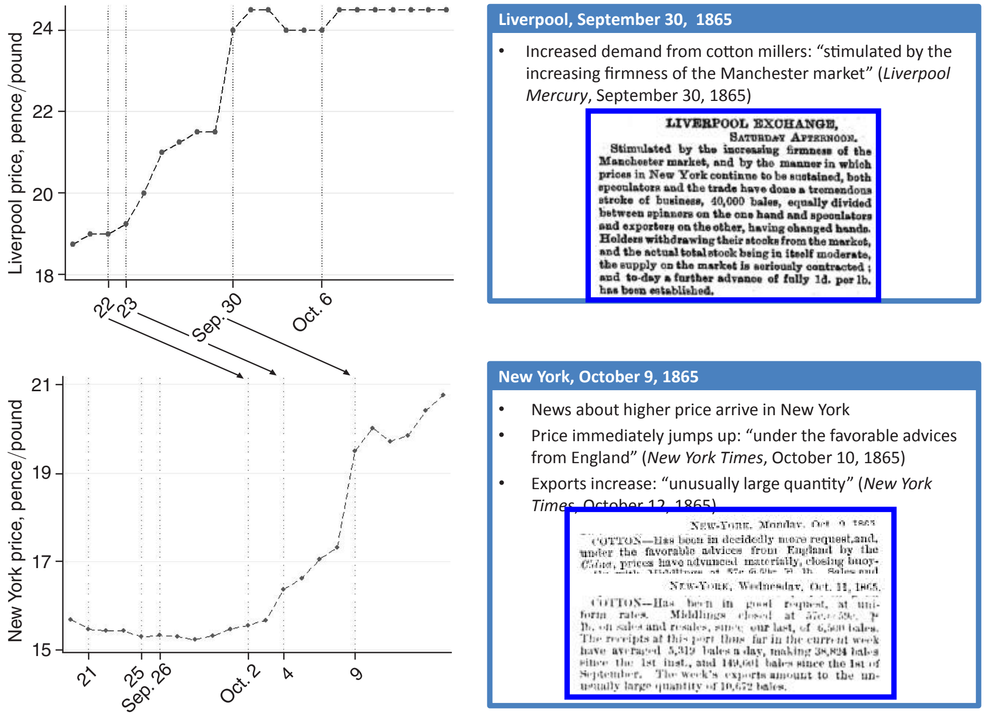

Figure 3. Reaction of New York Prices to News from Liverpool

C. New York Prices Responded Strongly to News from Liverpool, While Liverpool Prices Reacted Less Strongly to News from New York

The response of New York to news from Liverpool is best illustrated by the example in Figure 2 that explains the large upward spike in the price difference. Figure 3 drills down into this period: on September 30, 1865 the market in Liverpool experienced increased demand for cotton from spinners and millers. The *Liverpool Mercury* of that day reported that the market was "stimulated by the increasing firmness of the Manchester [yarn] market." At the same time, a mistake in the estimation of cotton stock in Lancashire was detected, leading to a downward correction. As a result, the Liverpool cotton price jumped by 12 percent within two days, from 21.5 to 24 pence/pound. However, due to the delayed information transmission by mail ships, market participants in New York were not aware of this demand shock. The next steam-ship, arriving in New York on October 2, still carried the outdated price information from September 23, a week before the demand shock. Only on October 9 did the news of the demand shock arrive, causing a jump in the New York cotton price as export demand increased. *The New York Times* reports an "unusually large quantity [of exports] under the favorable advices from England" on that day. This example also illustrates that information has real effects on export flows, and not just redistribution of profits across market participants.

To study more systematically whether news from Liverpool drove New York prices, column 1 in Table 4 starts with a parsimonious specification and regresses the New York price on a given day on the latest known price from Liverpool using only

Table 4—Impact of Telegraphed versus Steam-Shipped Liverpool Cotton Price on New York Cotton Price

Dependent variable: ln(New York price)	Before telegraph		After telegraph	
	(1)	(2)	(3)	(4)
ln(“telegraphed” Liverpool price)		0.002	0.734	0.710
		(0.066)	(0.061)	(0.065)
ln(“steam-shipped” Liverpool price)	0.434	0.434		0.069
	(0.032)	(0.032)		(0.064)
Observations	301	301	303	303

Notes: Columns 1 and 2 use only data from the pre-telegraph period; columns 3 and 4 use only data from the post-telegraph period. Counterfactual “telegraphed” price before telegraph is the Liverpool price in $t-1$. Counterfactual “steam-shipped” price after telegraph is Liverpool price in $t-10$. Prices are measured in pence/pound. Estimation of an AR(3) model with maximum likelihood. Standard errors in parentheses.

data from the pre-telegraph period. This latest known Liverpool price was transmitted by steam-ship, taking on average 10 days and is denoted “‘steam-shipped’ Liverpool price” in the table. To account for autocorrelation in prices, I implement maximum likelihood estimation including three lags of the dependent variable.

The coefficient on this latest known Liverpool price is positive, indicating a systematic reaction of the New York price to news from Liverpool. Since prices are serially correlated, it is possible that this coefficient reflects something other than the “news” about Liverpool. Therefore, column 2 includes a “counterfactual” price: the Liverpool price from the previous day, which was unknown to New Yorkers before the telegraph connection. Reassuringly, this unknown price has no impact on New York prices, while the coefficient on the steam-shipped price remains the same. Columns 3 and 4 perform the corresponding analysis for the period after the telegraph was established. The “telegraphed” Liverpool price, on average one day old, becomes the major driving force of the New York price, and the outdated price information that the steam-ship would previously have brought no longer matters. Note that the reaction of the New York price to the most recent Liverpool price is actually stronger after the telegraph. This makes sense, and is in line with the model that I will present later: merchants react more strongly to more recent information, probably because they understand that it is a better predictor of future market conditions.[13]

Liverpool prices also respond to information about prices in New York: in Table 5 we can see that the latest news about the New York price influences the Liverpool price, rather than a counterfactual telegraphed price or a counterfactual steam-shipped price. However, the elasticity of Liverpool prices to information about New York is much smaller than the elasticity of New York prices to information about Liverpool. This seems puzzling at first: why did Liverpool importers react to news much less strongly than New York exporters? Notice however that importers in England would always have to send their import orders by mail to New York. By

[13] This parsimonious specification is the most efficient regression to demonstrate the changing relevance of Liverpool’s prices on the New York market, as it explicitly uses the timing of information arrivals. As an alternative specification I provide in the online Appendix a vector autoregression using both prices separately, before and after the telegraph. Before the telegraph, only lags on the Liverpool price longer than 10 days are relevant for the New York price. After the telegraph, lags between 1–5 days are most relevant, in line with the distribution of information lags in Figure 1.

TABLE 5—IMPACT OF TELEGRAPHED VERSUS STEAM-SHIPPED NEW YORK PRICE ON LIVERPOOL PRICE

Dependent variable: ln(Liverpool price)	Before telegraph		After telegraph	
	(1)	(2)	(3)	(4)
ln("telegraphed" New York price)		−0.036 (0.051)	0.088 (0.046)	0.087 (0.047)
ln("steam-shipped" New York price)	0.082 (0.043)	0.082 (0.043)		0.016 (0.056)
Observations	301	301	303	303

Notes: Columns 1 and 2 use only data from the pre-telegraph period; columns 3 and 4 use only data from the post-telegraph period. Counterfactual "telegraphed" price before telegraph is the New York price in $t-1$. Counterfactual "steam-shipped" price after telegraph is New York price in $t-10$. Prices are measured in pence/pound. Estimation of an AR(14) model with maximum likelihood. Standard errors in parentheses.

the time orders arrived in New York, there would be more up-to-date information, and importers were wise enough to use this information by having subsidiaries or agents in New York, to whom they could give instructions contingent on actual supply shocks in New York. This explains why the behavior of importers in Liverpool does not affect prices much in response to news from New York.

Besides merchants, stock holders in Liverpool could potentially influence the Liverpool price in response to news from New York, by selling or holding onto their stock. For example, if they heard about a positive supply shock in New York, they would expect this supply to arrive in Liverpool in two weeks, depressing prices then. So storers would be wise to sell some of their stock now while the price remains high, which would be reflected in the Liverpool price responding to news from New York. However, in the presence of uncertainty about future demand and supply, it was very difficult for storers to determine the optimal day to sell stock. Storers postponing buying and selling decisions in the hope of better prices in the future may explain the lower elasticity in Liverpool.

D. The Telegraph Reduced the Mean and Volatility of the Difference between the Current Price in New York and the Latest Known Price in Liverpool

The results above suggest that market participants reacted to news about Liverpool prices. Did market participants in New York try to equalize the difference between the current New York price and the latest Liverpool price they actually observed? If so, we should not expect to see an effect of the telegraph on the *lagged* price difference, $p_{t-l_t}^{LIV} - p_t^{NY} - \tau$. In contrast to the previous studies on the effect of the telegraph on financial markets, I have the most recent Liverpool price that New York merchants observed for any given day in the sample, and can therefore test this relationship. Interestingly, even the average lagged price difference is reduced after the telegraph, as shown in column 2 of Table 6. Column 4 shows that the drop in the variance of the price difference is reduced by two-thirds, but there remains a significant effect of the telegraph (see the online Appendix for a graph).

These novel results suggest that merchants did not merely assume that the most recently observed price in Liverpool would still hold when their current shipments arrived. Instead, the merchants used the lagged, known price as the basis for

Table 6—Effect of Telegraph on the Difference between Lagged, Known Liverpool Cotton Price and Current New York Cotton Price

	$p_t^{LIV} - p_t^{NY} - \tau_t$ (1)	$p_{t-l_t}^{LIV} - p_t^{NY} - \tau_t$ (2)	$\widehat{\text{var}}$ of $p_t^{LIV} - p_t^{NY} - \tau_t$ (3)	$\widehat{\text{var}}$ of $p_{t-l_t}^{LIV} - p_t^{NY} - \tau_t$ (4)
Constant	1.45	1.78	2.15	1.02
	(0.16)	(0.11)	(0.40)	(0.14)
Telegraph dummy	−0.91	−1.18	−1.97	−0.64
	(0.15)	(0.10)	(0.43)	(0.12)
Cotton supply$_{t-1}$	0.13	0.10	0.01	−0.06
	(0.03)	(0.02)	(0.08)	(0.02)
Observations	575	575	575	575

Notes: Transport costs τ_t include freight cost and other transport cost. The sample excludes the no-trade period in May 1866. Column 1 repeats column 2 in Table 2. Column 2 uses a different dependent variable, $p_{t-l_t}^{LIV} - p_t^{NY} - \tau_t$,where $p_{t-l_t}^{LIV}$ is the latest Liverpool price that is known in New York, i.e., l_t denotes the information lag or travel time of information across the Atlantic. The information lag is not constant, but varies by day depending on actual data. Similarly, column 3 repeats column 5 in Table 2. Column 4 uses $p_{t-l_t}^{LIV}$ instead of p_t^{LIV} to create the price difference. $\widehat{\text{var}}(pdiff_t) := \frac{N_{before}}{N_{before}-1}(pdiff_t - \overline{pdiff}_{before})^2$ if the observation is before the telegraph, and $\widehat{\text{var}}(pdiff_t) := \frac{N_{after}}{N_{after}-1}(pdiff_t - \overline{pdiff}_{after})^2$ if the observation is after the telegraph. This implies that the coefficient on the constant yields the sample variance on the period before the telegraph, and the coefficient on the telegraph dummy yields the change in the sample variance before versus after the telegraph. Newey-West standard errors in parentheses (lag = 2).

predicting the future Liverpool price. Before the telegraph, the lagged Liverpool price was more outdated and had to be more heavily discounted when predicting the future. The difference between the lagged, known Liverpool price and the current New York price (which reflects merchants' expectations about future Liverpool prices) should therefore be less volatile after the telegraph, when information is more recent. For this reason the model in my theoretical section will feature rational merchants who use their expectations of the selling price in Liverpool as basis for arbitrage, $E\left[p_{t+k}^{LIV}\right] - p_t^{NY} - \tau$. While the last known, lagged Liverpool price p_{t-l}^{LIV} most likely informs the expected price $E\left[p_{t+k}^{LIV}\right]$, I abstract from naïve merchants who would set them equal to each other.

The observation that even the lagged price difference falls on average after the telegraph is consistent with two explanations. First, competition among merchants could be fiercer after the telegraph, leading to a reduction in the average markup. Second, the telegraph could have reduced uncertainty and risk, which would be reflected in a reduction in the risk premium of merchants in trade. Notice that the evidence on Herfindahl indices discussed earlier suggests that competition stayed constant, which is inconsistent with a change in markups. Instead, there is ample evidence in historical articles that risk mattered to merchants, and that the telegraph reduced it substantially (e.g., Ellison 1886; Hammond 1897). For this reason I will consider an extension of my model with risk-averse merchants in the theory section.

E. Exports Respond to News about Liverpool Prices

The analysis so far has considered only prices as outcomes. But does information have real effects? The detailed daily data on export flows can be used to understand whether the observed changes in the price difference are driven by equivalent changes in exports.

TABLE 7—IMPACT OF KNOWN LIVERPOOL COTTON PRICE ON EXPORTS

Dependent variable: ln(exports)	Before telegraph			After telegraph		
	(1)	(2)	(3)	(4)	(5)	(6)
ln("telegraphed" Liverpool price)		0.004 (1.015)	0.239 (1.109)	1.497 (1.856)	1.608 (2.352)	2.285 (2.460)
ln("steam-shipped" Liverpool price)	2.398 (0.659)	2.395 (1.046)	2.601 (1.052)		−0.164 (2.478)	0.827 (2.449)
Linear time trend			Yes			Yes
Observations	217	217	217	234	234	234

Notes: Columns 1 to 3 use only data from the pre-telegraph period; columns 4 to 6 use only data from the post-telegraph period. Counterfactual "telegraphed" price before telegraph is the Liverpool price in $t-1$. Counterfactual "steam-shipped" price after telegraph is the Liverpool price in $t-10$. Exports are measured in bales; Liverpool price is measured in pence/pound. Estimation of an AR(14) model with maximum likelihood. Standard errors in parentheses.

Table 7 uses a specification similar to that in Table 4 with exports as outcome and tests whether news about Liverpool prices affects exports. Column 1 uses only data from the year before the telegraph and shows that news of an increase in the Liverpool price leads to increased exports. Again, this news brought by steam-ship was around 10 days old. Column 2 conducts a placebo test and includes the unknown Liverpool price from the previous day, called "telegraphed" price. This counterfactual "news" has no significant impact on exports, as we would expect. Column 3 adds a linear time trend to control for a potential build-up of supply after the American Civil War. Columns 4 to 6 conduct a similar analysis for the period after the telegraph. News about the Liverpool market again has a positive effect on exports, but the coefficient is not significant due to large standard errors. Column 5 adds the Liverpool price that market participants would have known had there been no telegraph. The news from the steam-ship does not have a positive impact on exports, but the results are only suggestive, as standard errors are large. Column 6 allows for a linear time trend; the results remain unchanged. While the coefficient on the known Liverpool price is smaller, equality of the coefficients before and after the telegraph cannot be rejected. However, it might be rational for merchants to become less "responsive" to prices after the telegraph. Before the telegraph, the information about a demand shock was older. With autocorrelated demand shocks, more periods with high demand had already passed, leading to a more depleted stock in Liverpool. Foreseeing this, it was rational for merchants to export more upon receipt of such news before the telegraph, compared to after.

F. After the Telegraph, Exports Are on Average Higher and More Volatile

Column 1 in Table 8 shows that average daily exports from New York to Liverpool increased by 37 percent after the telegraph.[14] Column 1 in Table 9 shows that the variance of exports increased even more, by 114 percent.[15]

[14] 0.17/0.46 = 37 percent.
[15] 0.33/0.29 = 114 percent. A graph of daily exports is provided in the online Appendix.

Table 8—Effect of Telegraph on Average Cotton Exports from New York to Liverpool

	exp_t (1)	exp_t (2)	exp_t (3)	exp_t (4)	exp_t (5)	exp_t (6)	exp_t (7)	$\ln(exp_t)$ (8)	$\ln(exp_t)$ (9)
Constant	0.46	−0.34	−1.09	0.51	−1.07	0.30	−1.04	9.54	8.38
	(0.04)	(0.11)	(0.21)	(0.04)	(0.25)	(0.06)	(0.25)	(0.69)	(0.67)
Telegraph dummy	0.17	0.33	0.47	0.13	0.47	0.19	0.47	0.20	0.63
	(0.08)	(0.07)	(0.09)	(0.08)	(0.10)	(0.09)	(0.10)	(0.12)	(0.14)
Transport costs τ_t		2.10	1.50		1.49		1.36		1.85
		(0.30)	(0.22)		(0.24)		(0.24)		(0.38)
Cotton supply$_{t-1}$						0.07	0.03		
						(0.02)	(0.01)		
ln(cotton supply$_{t-1}$)								0.19	0.13
								(0.05)	(0.04)
Transport costs τ_t include									
Freight cost		Yes	Yes		Yes		Yes		Yes
Other transport costs			Yes		Yes		Yes		Yes
Excluding no-trade periods				Yes	Yes	Yes	Yes	Yes	Yes
Observations	604	604	604	575	575	575	575	443	443

Notes: Exports exp_t are in thousand bales. Column 2 controls for freight cost, and column 3 controls for additional transport cost (for details, see online Appendix). From column 4 on, the period of around four weeks during May 1866 (when exporters were inactive because the price in New York exceeded the price in Liverpool) is excluded. From column 6 on, the one day lagged cotton supply (receipts, in thousand bales) is used to control for potential disruptions in cotton production after the American Civil War. Newey-West standard errors (lag = 4) in parentheses.

The remaining columns in Table 8 present robustness checks for average exports similar to the ones implemented for the price difference. The increase in average exports after the telegraph connection cannot be explained by a fall in freight cost (column 2) or total transport costs (column 3). However, since transport cost might be endogenous, I report the remaining robustness checks in this table both with and without transport cost as controls. Columns 4 and 5 exclude no-trade periods, and columns 6 and 7 include the cotton receipts at the New York exchange from the fields to control for possibly expanding cotton production after the American Civil War.[16] Columns 8 and 9 use log of exports as a dependent variable.[17] Overall, the regressions show a consistent positive effect of the telegraph on trade.

Is it possible that we see increased exports because the telegraph caused cotton suppliers to reroute shipments from Southern ports through New York? As a robustness check, I collected data on aggregate world exports from the United States and from the second most important port, New Orleans, which were available weekly in *The Commercial & Financial Chronicle*. In the online Appendix I show that the telegraph has a positive effect on both world exports from New Orleans and total United States world exports, so the findings in Table 8 cannot be explained by rerouting shipments.[18]

[16] Alternatively, I run regression specifications as in Table 8 using cotton receipts as a dependent variable. Depending on the specification, cotton receipts either fall or do not change after the telegraph, so an increase in cotton production cannot explain increased exports.

[17] A full replication of this table with log exports as dependent variable is implemented in the online Appendix.

[18] I thank an anonymous referee for suggesting this analysis. Detailed results and data descriptions are provided in the online Appendix. Note that this is consistent with the previous findings which control for rerouting in an alternative way by controlling for cotton receipts which include shipments from Southern ports to New York.

TABLE 9—EFFECT OF TELEGRAPH ON THE VARIANCE OF COTTON EXPORTS FROM NEW YORK TO LIVERPOOL

	$\widehat{\text{var}}(exp)$ (1)	$\widehat{\text{var}}(exp)$ (2)	$\widehat{\text{var}}(exp)$ (3)	$\widehat{\text{var}}(exp)$ (4)	$\widehat{\text{var}}(exp)$ (5)	$\widehat{\text{var}}(exp)$ (6)	$\widehat{\text{var}}(exp)$ (7)	$\widehat{\text{var}}(exp)/\overline{exp}$ (8)	$\widehat{\text{var}}(exp)/\overline{exp}$ (9)
Constant	0.29	−0.39	−0.94	0.30	−1.03	0.10	−1.00	0.26	−1.59
	(0.04)	(0.22)	(0.39)	(0.04)	(0.47)	(0.07)	(0.46)	(0.13)	(0.74)
Telegraph dummy	0.33	0.46	0.57	0.32	0.61	0.38	0.61	0.49	0.88
	(0.12)	(0.14)	(0.17)	(0.12)	(0.19)	(0.13)	(0.19)	(0.21)	(0.31)
Transport costs τ_t		1.77	1.19		1.26		1.11		1.89
		(0.58)	(0.39)		(0.44)		(0.44)		(0.71)
Cotton supply$_{t-1}$						0.07	0.04	0.11	0.06
						(0.02)	(0.02)	(0.03)	(0.03)
Transport costs τ_t include:									
Freight cost		Yes	Yes		Yes		Yes		Yes
Other transport costs			Yes		Yes		Yes		Yes
Excluding no-trade periods				Yes	Yes	Yes	Yes	Yes	Yes
Observations	604	604	604	575	575	575	575	575	575

Notes: $\widehat{\text{var}}(pdiff_t) := \frac{N_{before}}{N_{before}-1}(pdiff_t - \overline{pdiff}_{before})^2$ if the observation is before the telegraph, and $\widehat{\text{var}}(x_t) := \frac{N_{after}}{N_{after}-1}(pdiff_t - \overline{pdiff}_{after})^2$ if the observation is after the telegraph. This implies that the coefficient on the constant yields the sample variance on the period before the telegraph, and the coefficient on the telegraph dummy yields the change in the sample variance before versus after the telegraph. Exports are in thousand bales. Controls are as in Table 8. Newey-West standard errors (lag = 2) in parentheses.

Table 9 conducts the same robustness checks for the variance of exports. Again, the increase in variance after the successful telegraph connection cannot be explained by these alternative hypotheses. To account for the increase in average exports, columns 8 and 9 use the variance of exports divided by average export (which is similar to the coefficient of variation) as a dependent variable, but results are unchanged.[19]

The following section provides an intuitive model of how information influences the behavior of exporters, yielding predictions consistent with the presented reduced-form findings.

IV. Model of Information Frictions in International Trade

I add information frictions to a basic two-country trade partial-equilibrium model with storage (based on Williams and Wright 1991 and Coleman 2009) by changing the information set of market participants. The model mimics cotton trade in the nineteenth century by focusing on the role of intermediaries in trade and showing how information frictions affect export decisions.

Cotton is elastically supplied by producers in country *NY* as given by the linear aggregate inverse (net) supply function $p^S(q_t) = \overline{a}_S + b_S q_t$. Intermediaries buy cotton in *NY* and ship it to another country *LIV*, where they sell it to consumers.[20] Shipping takes one period and costs τ per unit shipped.[21] Merchants are perfectly competitive and risk neutral. Aggregate consumer demand in *LIV* is stochastic and

[19] The full set of results for the variance of exports normalized by average exports (similar to the coefficient of variation) is provided in the online Appendix. I am grateful to an anonymous referee for pointing out that the increased volatility of exports in the post-telegraph period could also be explained by a banking crisis in May 1866. In the online Appendix I show that the results are robust to the inclusion of a banking crisis dummy.

[20] If cotton was not exported, it could either be stored or bought by domestic cotton millers (mostly from New England). The supply function should therefore be interpreted to be net of domestic demand.

[21] The numerical predictions are robust to allowing for ad valorem instead of unit trade cost.

given by a linear inverse demand function with stochastic, autocorrelated intercept, $p_t^D(q_t) = a_{Dt} - b_D q_t$, where a_{Dt} follows a stationary autoregressive process of order 1 around mean $\overline{a}_D$: $a_{Dt} - \overline{a}_D = \rho_D(a_{D,t-1} - \overline{a}_D) + \epsilon_t$ with $\epsilon_t \sim N(0, \sigma^2)$ and $0 < \rho < 1$.[22] In *LIV* there are storers who can buy cotton, store it for one period, and sell it in the next period. Holding the good for more than one period is equivalent to storers selling their stored quantity and buying it immediately back to store it for another period, i.e., revaluing their stock every period. Storage costs are θ per unit stored for one time period. Storers are perfectly competitive and risk neutral.

Maximization Problem of Merchants.—The representative merchant i chooses exports x_{it} that maximize expected profits conditional on his information set I_t^M:

$$\max_{x_{it} \geq 0} E\left[\left(p_{t+1}^{LIV} - p_t^{NY} - \tau\right) x_{it} \,\middle|\, I_t^M\right].$$

Exports are restricted to be nonnegative, because with time-consuming shipping, negative exports are equivalent to imports from a future period, which is not possible. As merchants are price takers, this maximization problem is linear with first-order conditions (FOC) $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} - \tau = 0$ if $x_{it} > 0$ and $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} - \tau \leq 0$ if $x_{it} = 0$. Aggregate exports are $x_t = \sum_i x_{it}$. The no-arbitrage condition at the industry level is[23]

$$E\left[p_{t+1}^{LIV} \mid I_t^M\right] \leq p_t^{NY} + \tau \perp x_t \geq 0. \tag{1}$$

Merchants choose exports that equalize the difference between expected prices in *LIV* in the next period and current prices in *NY*, subject to transport cost, except if expected prices in *LIV* are too low and it is not optimal to export at all. In either case, expected profits of merchants are zero, but realized profits may be positive or negative at any point.

Maximization Problem of Storers.—The maximization problem of the representative storer j is similar, but now arbitrage is across time instead of space. Each storer chooses stock s_{jt} to maximize expected profits, conditional on his information set I_t^S:

$$\max_{s_{jt} \geq 0} E\left[\left(p_{t+1}^{LIV} - p_t^{LIV} - \theta\right) s_{jt} \,\middle|\, I_t^S\right].$$

Storers are also price takers, and first-order conditions are: $E\left[p_{t+1}^{LIV} \mid I_t^S\right] - p_t^{LIV} - \theta = 0$ if $s_{jt} > 0$ and $E\left[p_{t+1}^{LIV} \mid I_t^S\right] - p_t^{LIV} - \theta \leq 0$ if $s_{jt} = 0$.[24] Aggregate storage is $s_t = \sum_j s_{jt}$. The no-arbitrage condition at the storage industry level is

$$E\left[p_{t+1}^{LIV} \mid I_t^S\right] \leq p_t^{LIV} + \theta \perp s_t \geq 0. \tag{2}$$

[22] The demand function is similar to Evans and Harrigan (2005), with an autocorrelated demand process.

[23] The sign $\perp$ denotes a mixed complementarity problem that is equivalent to two conditions: either $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} = \tau$ and $x_t > 0$; or $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} \leq \tau$ and $x_t = 0$. If $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} > \tau$ merchants would like to export an infinite amount, which is not an equilibrium. If $E\left[p_{t+1}^{LIV} \mid I_t^M\right] - p_t^{NY} = \tau$, individual merchants are indifferent about how much to export, and in equilibrium aggregate exports are determined by market-clearing conditions.

[24] Note that equivalently, the problem can also be formulated using value functions (as in Williams and Wright 1991, p. 53), because consumer demand is assumed to be intertemporally separable.

Storers increase storage until expected prices in *LIV* in the next period are equal to today's prices in *LIV* plus storage cost, unless expected prices are too low to make profits from storage. The expected profits of storers is zero, but like merchants, storers may realize profits or losses in any specific period.

Note that a particular feature of commodity storage models is that it is not possible for the market as a whole to store negative quantities. While each individual stock holder could in principle store a "negative amount" (that is, selling "short") by borrowing the commodity from other storers, selling it on the spot market, buying the same amount of stock in the next period, and returning it to the lender, this is not true for the market as a whole (Williams and Wright 1991).

Information Frictions.—Decisions about storage and exports are based on expected prices in *LIV* conditional on the information set of the respective agents. I consider two different information regimes:

- *Delayed Information* (*DI*). Assume merchants are based in *NY*, where they make their exporting decision by buying from suppliers.[25] They possess information about all shocks in *LIV* up to period $t-1$ and must forecast *LIV* prices in period $t+1$, when their exports can be sold in *LIV*. Similarly, storers are based in *LIV*, where they make their storage decisions. They have information about demand shocks in *LIV* up to period t when forecasting *LIV* prices for period $t+1$ and information about *NY* up to the previous period $t-1$.
- *Instantaneous Information* (*II*). All market participants are informed about demand shocks in *LIV* up to period t when forecasting expected prices in period $t+1$.

Below I refer to the *DI* regime as having "information frictions." The introduction of the telegraph can be interpreted as a reduction in (or almost elimination of) information frictions.

Equilibrium Conditions.—Equilibrium is determined by the FOC of merchants (1) and storers (2) and market-clearing conditions in both countries. In *NY* elastic supply meets the export demand of merchants:

$$p_t^{NY} = \bar{a}_S + b_S x_t. \tag{3}$$

In *LIV* supply is given by imports (equal to the amount of goods exported from *NY* in the previous period) plus storage from the previous period s_{t-1}, while demand is by consumers and storers:

$$p_t^{LIV} = a_{Dt} - b_D(x_{t-1} + s_{t-1} - s_t). \tag{4}$$

[25] In practice, merchants had representatives (usually family members) in both New York and Liverpool. If a merchant was in Liverpool, he would have had to travel to (or communicate with) New York to export cotton from Liverpool to New York, and therefore would have the same information as a merchant already based in New York. Therefore we can assume that merchants are based in New York only.

Analytical Expressions.—The FOC for merchants (1) together with market-clearing conditions (3) and (4) yield analytical expressions for exports and the price difference, which are useful for intuition and interpretation. Exports depend on expected demand shocks and expected change of stock in period $t+1$, when the shipment arrives in *LIV*, conditional on the information of merchants:

$$(5) \qquad x_t = \max\left\{ \frac{E\left[a_{D,t+1} + b_D s_{t+1} - b_D s_t \middle| I_t^M\right] - \bar{a}_S - \tau}{b_S + b_D}, 0 \right\}.$$

The price difference adjusted for shipping time is equal to the error made in forecasting demand shocks and changes in stock, if exports are positive, and the price difference is determined by local supply and demand conditions if exports are zero:

$$(6) \quad pdiff_{t+1} := p_{t+1}^{LIV} - p_t^{NY} - \tau$$

$$= \begin{cases} a_{D,t+1} - E\left[a_{D,t+1} \middle| I_t^M\right] + b_D\left(\Delta s_{t+1} - E\left[\Delta s_{t+1} \middle| I_t^M\right]\right) & \text{if } x_t > 0 \\ a_{D,t+1} + b_D(s_{t+1} - s_t) - a_S - \tau & \text{if } x_t = 0 \end{cases}.$$

Storage is endogenous, as it depends on the information regime and cannot be solved for analytically (Deaton and Laroque 1996; Williams and Wright 1991).

Numerical Solution and Calibration.—I adjust numerical solution approaches developed by the commodity storage literature (e.g., Coleman 2009; Williams and Wright 1991; Deaton and Laroque 1996) to allow for different types of information sets of agents that affect how expectations are formed. Details of the numerical solution and the calibration of parameters can be found in the online Appendix.

No Storage.—For intuition, consider first the case without storage. Consider a demand shock.[26] Under delayed information, exporters in *NY* do not know about the demand shock upon impact, and therefore there is no immediate response in exports. Prices in *LIV* increase due to the unsatisfied demand, while prices in *NY* stay the same. The difference between the price in *LIV* during the next period and the current price in *NY*—the relevant price difference for arbitrage—increases as prices in *LIV* go up. In the next period exporters learn about the demand shocks and adjust exports upward, which increases prices in *NY*, but it takes another period for exports to arrive in *LIV* and prices to fall. Thus, it takes two periods after the shock for the price difference to return to zero.

Under instantaneous information, adjustment is faster: exports increase immediately, driving up the price in *NY*. There is still a spike in the *LIV* price because of the shipping delay. The shipping time-adjusted price difference increases for one period as well, as exporters make unexpected profits, but adjusts in the next period as exporters arbitrage away these profits.

[26] Figures of impulse-response functions that illustrate this narrative are provided in the online Appendix.

TABLE 10—CHANGE FROM DELAYED TO INSTANTANEOUS INFORMATION REGIME (*Percent*)

		Model				
Storage cost:	Data	No storage	0.25	0.10	0.0229	0.01
Panel A. No supply shock						
Price difference: $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$						
Mean	−49.3	−49.5	−53.6	−88.1	−207.9	−223.9
Variance	−94.8	−33.7	−39.1	−43.6	−46.9	−46.6
Exports						
Mean	37.7	4.2	3.6	1.9	0.8	0.5
Variance	199.4	26.0	24.0	19.3	12.3	7.7
Share of periods with zero trade	−3pp	3.8	3.6	1.6	0.02	<0.01
Storage						
Mean	53.2	N/A	−7.4	−4.0	−1.5	−1.0
Variance	−49.2	N/A	−6.2	−3.5	−1.3	−0.7
Panel B. Supply shock						
Price difference: $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$						
Mean	−49.3	−18.1	−15.8	−8.1	−1.3	−0.7
Variance	−94.8	−25.6	−28.0	−23.6	−6.5	−1.1
Exports						
Mean	37.7	3.3	3.0	1.4	0.3	0.4
Variance	199.4	14.3	12.6	7.6	1.8	0.8
Share of periods with zero trade	−3pp	1.6	1.3	0.9	0.9	0.5
Storage						
Mean	53.2	N/A	−2.2	−4.1	−5.8	−6.7
Variance	−49.2	N/A	−1.7	−3.9	−3.0	−7.9
Panel C. Risk premium						
Price difference: $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$						
Mean	−49.3	−477.1	−515.8	−319.2	−200.5	−181.5
Variance	−94.8	−34.8	−39.6	−41.4	−42.7	−43.5
Exports						
Mean	37.7	36.3	36.0	36.0	39.4	41.8
Variance	199.4	42.2	41.2	34.3	28.4	28.2
Share of periods with zero trade	−3pp	−7.7	−8.0	−9.6	−10.8	−11.1
Storage						
Mean	53.2	N/A	−3.7	−4.4	−5.3	−6.3
Variance	−49.2	N/A	−5.9	−5.9	−3.7	−8.6

Notes: Change is from delayed (= before telegraph) to instantaneous (= after telegraph) information regime, in percent of the variable in the delayed information regime. Summary statistics are based on data aggregated over 10 days. Price difference is net of total transport cost. Storage cost of 0.0229 are given by historical accounting statements of merchants, while storage cost of 0.25 are consistent with the average stock-to-export ratio in the data. The true storage cost was probably within this range of values. Model predictions are based on a simulation of the model over 10,000 periods.

I simulate the model over 10,000 periods for both information regimes to compute summary statistics. The second column in panel A of Table 10 shows that the predictions of the model without storage match the empirical results: the model predicts a fall in the average price difference and in the variance of the price difference, and an increase in average exports and the variance of exports.

For the intuition of these results, consider equation (5) (setting storage to zero). Exports are a function of expected demand shocks. The distribution of expected demand depends on the information regime. With more information, the variance of expected demand is higher. Consider two extremes. Without any information, expected demand is a constant with zero variance. With perfect foresight, expected demand is actual demand and has the variance of the demand shock. In between, more information leads to a higher variance in expected demand, and therefore exports. The following lemma shows this formally.

LEMMA 1: *When switching from delayed to instantaneous information, the variance of expected demand increases,*

$$\mathrm{var}\Big[E\big[a_{D,t+1}\,|\,I_{t-1}^{M}\big]\Big] \;<\; \mathrm{var}\Big[E\big[a_{D,t+1}\,|\,I_{t}^{M}\big]\Big].$$

PROOF:
See online Appendix.

The magnitude of the change depends on the autocorrelation coefficient in a nonlinear way and is largest with an autocorrelation coefficient of around 0.7. More persistence means information is less important because even the lagged demand shock is a good predictor of the future, and less persistence means that even current shocks are not very informative about future shocks. However, as persistence falls, the variance of expected demand also falls, and the percentage change in the variance increases monotonically.[27]

Since exports cannot be negative, this gives rise to a censoring of the distribution of expected demand, which increases average exports (both unconditional and conditional on exports being positive), as the following Lemma shows.

LEMMA 2: *Suppose* $\frac{\overline{a}_D - \overline{a}_S - \tau}{b_S + b_D} > 0$, *which means that there are positive exports at the average demand shock. Then, when switching from delayed to instantaneous information:*

(*i*) *Average exports increase,*

$$E\big[x_t^{DI}\big] \;<\; E\big[x_t^{II}\big].$$

(*ii*) *Conditional on exporting, exports increase,*

$$E\big[x_t^{DI}\,|\,x_t^{DI} > 0\big] \;<\; E\big[x_t^{II}\,|\,x_t^{II} > 0\big].$$

PROOF:
See online Appendix.

Censoring increases average exports, because in periods of very high demand, merchants know about it in the instantaneous information regime and export more. However, in periods of very low demand, exports are zero in both information regimes, and it does not matter whether merchants know exactly how low demand is. Censoring introduces an asymmetric effect on exports. The magnitude of this effect depends on how much the probability of zero exports increases, which is a nonlinear function of the autocorrelation coefficient and the variance of the demand innovations.

Merchants equalize expected prices across countries, and the resulting realized price difference equals the forecast error of merchants, as equation (6) shows. If merchants were not making any forecast error, which would happen if they could

[27] Except for the special case of a white noise shock process, for which the variance of expected demand is always zero and does not change because information is irrelevant.

foresee demand shocks, the lagged spatial price difference $pdiff_{t+1}$ would be zero, and the no-arbitrage condition would hold ex post. With information frictions or shipping time, the no-arbitrage condition holds only in conditional expectations, and merchants make a forecast error depending on the information they have. The volatility of forecast errors falls when more information becomes available (a result well established in the finance literature), which explains why the volatility of the price difference falls when switching from the *DI* to the *II* regime.

LEMMA 3: *When switching from delayed to instantaneous information*, *the variance of the forecast error falls*,

$$\text{var}\left[a_{D,t+1} - E\left[a_{D,t+1} \mid I^M_{t-1}\right]\right] \; > \; \text{var}\left[a_{D,t+1} - E\left[a_{D,t+1} \mid I^M_{t}\right]\right].$$

PROOF:

See online Appendix.[28]

The magnitude of this change grows with persistence.

The average price difference falls after switching to the *II* regime. This holds for the same reason that average exports increase. Under the *DI* regime, positive demand shocks are systematically underestimated, leading to high prices in *LIV* and a large price difference as exports are restricted. These positive price differences are eliminated under the *II* regime, as exports are sufficiently high. Note that this does not mean that merchants were making profits under the *DI* regime, as high ex post profits in cases when demand was higher than expected were offset by equivalently high losses in cases when demand was smaller than expected. Neither does this mean that merchants make losses under the *II* regime, as they avoid negative price differences by not exporting at all (when they would have exported under the *DI* regime).

Storage.—Storage reduces the effect of information frictions. When merchants overestimate demand and ship too much, part of the imports can be stored for the future and consumed when merchants underestimate demand and ship too little. Storage smooths demand shocks (Williams and Wright 1991, p. 43) and results in prices fluctuating less than in a model without storage (and showing a higher autocorrelation than the underlying shocks; Deaton and Laroque 1996).

When a demand shock hits, *LIV* prices in the same period go up, because the increased demand is not absorbed by increased imports (this occurs only in the next period due to the shipping delay), and it is only partially absorbed by an increased release from storage.[29] Why is it not optimal for storers to release enough stock to fully absorb the demand shock and therefore smooth prices perfectly? I present an indirect proof. Assume that storage is run down enough to satisfy the additional demand and that there is no price increase in *LIV*. Consider first the case in which exports increase to replenish the stock during the next period. Increased exports lead to increased *NY* prices, because the supply curve is upward sloping. Merchants export cotton at increased *NY* prices only if there is an equivalent increase in expected prices in *LIV*

[28] This result also holds if the demand shock is a random walk.

[29] Figures of impulse-response functions that illustrate the narrative are provided in the online Appendix.

during the next period. However, if expected prices in *LIV* during the next period rise, storers want to keep some stock to sell in the next period, and therefore they do not release it in the current period, which contradicts our assumption. Consider now the case in which exports do not increase to replenish the stock next period. Due to the stock release in the current period, stock will be lower than usual in the next period. If there is another high demand shock in the next period (which is highly probable with autocorrelated demand shocks but is possible even if demand shocks are i.i.d.), stock will be run down further. If imports never increase, at some point there will be stock-outs, which result in very high prices (only infinite stock can insure against stock-outs). Storers foresee this and therefore will not release all their stock in the current period, which is again a contradiction to our assumption. Overall, in equilibrium, stock will be released to *partially* but not fully offset demand shocks (lower storage cost will lead to larger stock releases), and exports will increase slightly over an extended period to slowly replenish stock to equilibrium levels. The larger the autocorrelation of the shock process, the less successful storage will be in smoothing prices.

If the storage technology were "perfect," prices would be completely stabilized and information would not matter. However, perfect storage requires an infinite amount of stock to insure against the small but positive probability that long periods of particularly high demand will run down inventories (Townsend 1977; Deaton and Laroque 1996; Williams and Wright 1991). As Williams and Wright (1991, p. 159) state, with aggregate demand shocks, "Storage is asymmetric—able to support a glut but not alleviate every shortage."

Because storage does not fully smooth prices, there is still a spike in the price difference adjusted for shipping time. The increased exports arrive in the next period, but the *LIV* price does not fall very much, as demand is still high. Stock no longer has to be run down as much to stabilize the price in *LIV*. The possibility of storage means that demand shocks are smoothed over time: exports do not have to increase immediately, thereby increasing the supplier price in *NY*, but instead can increase less but over a longer period, while stock is slowly built up again.

With delayed information, equilibrium stock is higher. When a demand shock hits, stock is released just as in the *II* regime. Since the exports increase only in the subsequent period, more stock needs to be released in order to smooth prices. The price difference adjusted by shipping time takes two periods to adjust.

Table 10 shows the changes in summary statistics of the numerical simulations for a variety of storage cost levels. The predictions of the model with storage are still in line with the data: average exports and the variance of exports increase, while the average price difference and the variance of the price difference fall. The smaller the storage cost, the smaller the absolute change in all of the moments. However, because the average and variance of the price difference become smaller, the percentage change due to reduced information frictions becomes larger. For storage cost of 0.0229 (which merchants report in historical accounting statements), the model can predict the drop in the average price difference quite well, and about one-half of the drop in the variance of the price difference.[30] The model is less

[30] Since the storage cost in the data is not as reliable as other numbers, I use an alternative calibration using the ratio of stock to exports, which corresponds to storage cost of around 0.25. More details are provided in the online Appendix.

successful in explaining the quantitative change in exports. However, when interpreting quantitative changes, note the following caveat. Since the daily model does not aggregate up nicely to the one-period (equivalent to roughly 10 days) model because of overlapping shipments, this simplified model should probably be used for qualitative rather than quantitative analysis.

The model also predicts the proportion of periods without trade to increase, as with a larger variance of expected demand the probability of expected demand being below the no-export threshold increases. This effect is dampened by storage, but is nonetheless inconsistent with the data, in which the share of zero trade periods actually falls.

The model also has two predictions for storage. First, information reduces the need for stock to smooth shocks, so after the telegraph, average stock should fall. Second, before the telegraph storage was adjusted in response to demand shocks because exports could not react immediately, while after the telegraph exports could react, reducing the need for storage to be adjusted, which results in a fall in the variance of stock. Only the second prediction is true in my data (whereas the first prediction becomes true in the long run, in the years after my data ends).

I will now provide two extensions of the basic model and discuss how well they match the data.

Supply Shocks.—For a more realistic model, I allow for stochastic supply shocks. Exports are then a function also of supply shocks, and storage in *LIV* depends on information about supply shocks: the current supply shock in the *II* regime, and the lagged supply shock in the *DI* regime.

Supply shocks affect the model in two ways. First, they increase baseline variability. Second, there is an additional impact of the telegraph: more information is not only relevant for merchants in *NY*, who learn about demand shocks in *LIV* sooner, but also for storers in *LIV*, who learn about supply shocks in *NY* sooner.[31] After the telegraph, storers in *LIV* can run down inventory, foreseeing increased imports next period due to a supply shock in *NY*, whereas before the telegraph, they could not respond. Panel B in Table 10 shows that this additional effect does not alter the qualitative prediction of the model, while the predicted effects are quantitatively smaller.

Risk Aversion.—The changes in average exports in the data are larger than the model predicts. One reason could be that in reality merchants were risk averse rather than risk neutral. The higher uncertainty in the delayed information regime leads risk-averse merchants to export less, exaggerating the effect of the telegraph.[32] This notion is also consistent with the reports of contemporary observers, which praise the telegraph for extensively reducing the risk for merchants. For example, Hammond (1897, p. 284–285) writes that the telegraph "diminished risk in buying cotton from America," as "the blind speculation of the importing merchant […] was replaced by a probability bordering on certainty." Panel C in Table 10 illustrates that

[31] See the online Appendix for empirical evidence on this.

[32] Allowing for imperfect competition among merchants would also yield these predictions. However, the Herfindahl indices in the online Appendix suggest that this explanation is unlikely.

it is possible to magnify the quantitative impact of the telegraph significantly by adding a constant risk premium to the *DI* regime.[33]

Reduced risk promotes trade, and this overturns the prediction of the baseline model with respect to periods with zero trade. In line with the data, the share of periods with no trade now falls by several percentage points.

All models consistently predict that average stock should fall after the telegraph, which is not the case in the data. One explanation to reconcile these findings could be that storers were not immediately fully aware of the potential of the telegraph to reduce the amount of stock necessary. This is certainly possible, as they were not aware of other potential uses of the telegraph either: e.g., the earliest accounts of transatlantic futures trades are from 1868 (Farnie 2004). In fact, aggregate annual stock data show that Liverpool stock amounted to about 15 percent in the 5 years before the telegraph (excluding the Civil War years), and fell to around 7 percent in the 5 years after the telegraph (see table in the online Appendix). A reduction in stock is therefore a more long-term benefit of the telegraph, resulting in welfare gains, as storage costs are reduced. However, as we do not see this in the data in the short term, the calculations of the efficiency gain from the telegraph in the next section do not include efficiency gains from reduced storage costs, and are therefore a lower bound on the long-run efficiency gains from the telegraph.

V. Efficiency Gains from the Telegraph

This section shows that a lower bound of the deadweight loss (DWL) from information frictions is a function of only three parameters: the squared observed price difference across markets, the slopes of the supply, and demand functions. This is an analytical result obtained from a more general version of the model presented above: it does not rely on the numerical solutions obtained in the previous section, nor on assuming a specific time series process for the demand and supply shocks, as observables are sufficient statistics for the underlying realized shocks. Furthermore, I use daily data for the estimation rather than ten-day periods as in the numerical model.

Regarding welfare in a dynamic storage model, I follow Williams and Wright (1991, p. 350), who measure the welfare generated in any period W_t as the sum of current consumer surplus CS_t, current producer surplus PS_t, current profits and losses of merchants MS_t and storers SS_t, and the *expected present value* of the net social surplus from current stock $ESS(s_t)$.[34] The latter captures increases in future consumer surplus upon consumption of the current stock as well as future reductions of producer surplus when releases of stock depress prices.

Current consumer surplus CS_t is given by the area underneath the consumer demand function minus the price paid. The expected net present value of the social surplus from the quantity stored $ESS(s_t)$ is given by the additional area under the market demand curve and the consumer demand curve, minus the price paid. Current producer surplus PS_t is given by the area above the supply curve up to the

[33] More information is provided in the online Appendix.

[34] In the online Appendix, I use an alternative approach that replaces the expected surpluses from stock with actual surpluses, using the cruder weekly stock data. Results are similar.

price received by producers when selling to merchants in *NY*. Current surpluses of merchants and storers, MS_t and SS_t, are given by their profits or losses. Current welfare is therefore[35]

$$W_t = \int_0^{x_{t-1}+s_{t-1}} p^M(q)\,dq - \int_0^{x_{t-1}} p^S(q)\,dq - p_{t-1}^{LIV} s_{t-1}. \tag{7}$$

This expression measures the welfare associated with a specific export quantity x_{t-1}, independent of how this export quantity is determined. Now consider the following counterfactual as a benchmark case: what would welfare have been, had merchants foreseen demand shocks and changes in stock? The exports in this benchmark case x_{t-1}^* would have been the efficient export quantity that maximizes welfare; denote this efficient welfare as W_t^*. Any deviation from efficient exports results in reduced welfare (holding everything else constant). Define deadweight loss in a specific period as the difference in welfare to the benchmark: $DWL_t = W_t^* - W_t$. The theorem below gives a lower bound for deadweight loss from information frictions.

THEOREM 1: *The deadweight loss from a specific export transaction* $x_{t-1} > 0$ *compared to exports in the benchmark case when merchants can foresee market demand, holding everything else constant, is bounded from below by* $\underline{DWL}$,

$$DWL(x_{t-1}) = W_t^* - W_t \geq \frac{\left(p_t^{LIV} - p_{t-1}^{NY}\right)^2}{2(b_D + b_S)} =: \underline{DWL}, \tag{8}$$

where prices p_t^{LIV} *and* p_{t-1}^{NY} *denote equilibrium prices associated with exports* x_{t-1}.

PROOF:

See online Appendix.

This formula shows that the observed spatial price difference $p_t^{LIV} - p_{t-1}^{NY}$, the slope of the demand curve b_D, and the slope of the supply curve b_S are sufficient statistics for the lower bound of the deadweight loss from information frictions.[36]

Note that the underlying assumption of the welfare calculation is that consumption is intertemporally separable in a very specific sense: consumers cannot intertemporally smooth consumption *except* by engaging in storage activities (the identity of storers in the model is undefined). Furthermore, as the demand function does not depend on income, there are also no income effects (with zero income elasticity, the Marshallian surplus is identical to the Hicksian compensating and equivalent variations each period). With these assumptions I follow the commodity storage literature (e.g., Williams and Wright 1991; Deaton and Laroque 1996; Coleman 2009) and focus on simply adding information frictions to existing models.

Considering the expression for the deadweight loss (equation (8)), it is not surprising that the deadweight loss from information frictions is a function of the

[35] A more detailed derivation is provided in the online Appendix.

[36] In the online Appendix, I provide figures representing how the efficiency loss due to information frictions can be illustrated using Harberger Triangles.

observed price difference. The LOP states that any spatial price difference gets arbitraged away if agents are fully informed (i.e., if merchants can foresee market conditions upon arrival of shipments). The literature on the LOP therefore interprets observed price difference as a measure of the underlying market frictions and its associated deadweight loss. The theorem makes the relationship between deviations from the LOP and efficiency explicit. Since both positive and negative deviations from the LOP cause efficiency losses, the second moment of the price difference has first-order implications on the deadweight loss (the price difference enters in a squared form).

I estimate the daily deadweight loss from information frictions by extending the formula above to a daily setting, while allowing for transport cost, $\frac{\left(p_t^{LIV} - p_{t-k}^{NY} - \tau_{t-k}\right)^2}{2(b_D + b_S)}$, where k denotes the actual shipping time in days, and the demand and supply elasticities are estimated based on daily data.

The observed price difference $p_t^{LIV} - p_{t-k}^{NY} - \tau_{t-k}$ falls dramatically after the telegraph. The fall in the price distortion after the telegraph is equivalent on average to a roughly 7 percent ad valorem tariff.[37] The largest price distortions during the pre-telegraph period are equivalent to an ad valorem tariff of up to 55 percent. For comparison, note that the average US tariff abolished during NAFTA in 1994 was 3 percent, while the highest abolished tariff was 12 percent, for textile trading with Mexico (Caliendo and Parro 2015).

To translate these price distortions into efficiency gains, I need estimates of the slopes of the supply and demand functions. Such estimates are often difficult to make, as quantities and prices are determined contemporaneously and finding a valid instrument is difficult. I propose a new identification strategy: since shipping takes time, exports are predetermined once they arrive in Liverpool, breaking the simultaneity problem for the case of i.i.d. shocks. For the case of autocorrelated shocks and positive storage, I use the model to control appropriately for the endogenous portion of the shocks, yielding identified regression equations.

Estimation of the Demand Curve.—The demand curve in Liverpool on a specific day $t + k$, where k indicates the time (in days) a shipment takes to get from New York to Liverpool, is determined by the realization of the demand shock on that day, $a_{D,t+k}$, the imports arriving in Liverpool on that day (which are equivalent to exports from New York k days earlier, x_t), and net take-up or release of stock from storage on that day, Δs_{t+k}:

$$p_{t+k}^{LIV} = a_{D,t+k} - b_D\left(x_t - \Delta s_{t+k}\right).$$

Daily prices in Liverpool as well as daily imports can be observed. The main identification problem is the unobserved demand shock that is positively correlated with change in stock and exports. Note that exports are a function of lagged demand

[37] The equivalent ad valorem tariff of the distortion is calculated for each day as the absolute price difference minus transport cost in percent of the lagged New York price p_{t-k}^{NY}. The average tariff equivalent is equal to the difference in the average of this measure between the pre- and post-telegraph periods. Days with no trade are excluded from this calculation.

shocks, which are correlated with demand shocks at $t+k$ only via the autocorrelation of the demand shock. My identification strategy will exploit this fact by modeling this dependence explicitly.

Assuming demand follows an AR(1) process around mean $\overline{a}_D$, we can express the demand shock in period $t+k$ in terms of the demand shock in period $t-l$, where l denotes the information delay between Liverpool and New York, and the sum of demand innovations between $t-l$ and $t+k$:

$$a_{D,t+k} = (1-\rho^{k+l})\overline{a}_D + \rho^{k+l} a_{D,t-l} + \sum_{i=0}^{k+l-1} \rho^i \epsilon_{D,t+k-i}.$$

We can use the lagged demand function to control for the lagged demand shock, as $p_{t-l}^{LIV} = a_{D,t-l} - b_D(x_{t-k-l} - \Delta s_{t-l}^{LIV})$. This results in an equation where all of the regressors except change in stock Δs_{t+k}^{LIV} are uncorrelated with unobserved demand shocks. Current imports x_t can be used as an instrument for $x_t - \Delta s_{t+k}^{LIV}$, however. Data on stock in Liverpool are available only at weekly intervals, so I distribute the weekly change equally across the days of the week, introducing a measurement error that is also addressed by the instrumental variables strategy. Table 11 shows the results of estimating the following equation:

$$(9)\quad p_{t+k}^{LIV} = \beta_0 + \beta_1(x_t - \Delta s_{t+k}^{LIV}) + \beta_2 p_{t-l}^{LIV} + \beta_3(x_{t-k-l} - \Delta s_{t-l}^{LIV}) + \sum_{i=0}^{k+l-1} \rho^i \epsilon_{D,t+k-i}.$$

Column 1 shows the OLS results and column 2 shows the IV results. The first stage is strong, as indicated by the F-statistics. The instrument addresses both the correlation of stock changes and demand shocks in the error as well as measurement error in the stock changes. The latter seems to dominate as the OLS estimate is biased toward zero. The sign of the lagged Liverpool price is positive and less than 1, as expected. In columns 3 and 4 the IV specifications are estimated separately for the period before and after the telegraph.[38]

The second-to-last row in Table 11 computes the demand elasticity at mean values of prices and quantities. The resulting demand elasticities seem rather high when compared to estimates of demand elasticity of cotton in the nineteenth century in the literature (Irwin 2003), which range between 1.7 and 2.3. Note, however, that the estimates in the literature are based on yearly instead of daily data. Daily demand elasticities are much higher because they take into account the willingness of consumers (or cotton millers) to substitute consumption across time, which is easier across short periods compared to long periods. To empirically validate this argument, I run the demand estimation on different aggregation periods of my data. Aggregating the data strongly reduces the demand elasticity. For example, for three-monthly data, the demand elasticity is as low as -2 (see the online Appendix for details on aggregation patterns).[39]

[38] Note that equation (9) implies a specific relationship between the coefficients that can be tested, i.e., $\beta_1 + \frac{\beta_3}{\beta_2} = 0$. The table reports χ^2-test statistics on this null hypothesis, which was not rejected except when restricting the analysis to the subsample after the telegraph.

[39] As an anonymous referee pointed out, due to the imperfect substitutability of cotton from different locations, the demand estimated here should be interpreted as residual demand after accounting for supply of other cotton.

Table 11—Estimation of the Slope of the Demand Function

Dependent variable: p^{LIV}_{t+k}	OLS (1)	IV (2)	IV (3)	IV (4)
$x_t - \Delta s^{LIV}_{t+k}$	−0.028	−0.050	−0.073	−0.031
	(0.015)	(0.020)	(0.033)	(0.019)
$p^{LIV}_{t-l_t}$	0.899	0.893	0.831	0.933
	(0.038)	(0.037)	(0.062)	(0.034)
$x_{t-k-l_t} - \Delta s^{LIV}_{t-l_t}$	0.019	0.021	0.040	−0.006
	(0.020)	(0.020)	(0.034)	(0.007)
Observations	506	506	258	248
R^2	0.852	0.852	0.698	0.879
First stage F-stat		284.0	136.2	243.2
First stage coefficient		0.707	0.775	0.634
		(0.042)	(0.066)	(0.041)
χ^2-test statistics: $\beta_1 = \frac{\beta_3}{\beta_2}$	0.081	0.727	0.289	4.465
p-value	0.776	0.394	0.591	0.035
Demand elasticity	−174.3	−98.6	−106.4	−102.1
Sample	Full sample	Full sample	Before telegraph	After telegraph

Notes: Prices are denoted in pence/pound. The quantities in the regressor are given in 1,000 bales (1 bale ≈ 400 pounds). Index k denotes shipping time from New York to Liverpool, and l_t denotes information delay between Liverpool and New York. The sample size is smaller than in the other regression tables, because stock information is sometimes missing, in particular at the end of each quarter (for more details, see the online Appendix). HAC standard errors in parentheses.

Estimation of the Supply Curve.—The slope of the supply function is estimated in a similar way. To better match the data, the supply function given by equation (3) is extended by allowing both for supply shocks and for storage in New York:

$$p^{NY}_t = b_S\big(\Delta s^{NY}_t + x_t\big) + a_{St}.$$

Again, the problems in estimating this equation are twofold. First, NY stock data are available only at weekly intervals, so I distribute the weekly change equally across days, introducing measurement error. Second, exports and stock changes are correlated with current supply shocks. I add a dummy for the harvest year and include a quadratic in the day of the harvest year to model supply fluctuations, but as this cannot fully address endogeneity concerns, I pursue an instrumental-variables approach for the estimation. In column 2 of Table 12, I use known prices from Liverpool, p^{LIV}_{t-l}, as an instrument for the sum of export and stock changes, $\Delta s^{NY}_t + x_t$. The first stage is strong, as information about the latest prices from Liverpool influences exports and stock changes positively. If supply shocks are correlated, however, lagged Liverpool prices might reflect lagged supply shocks, and not be exogenous. Therefore, I use implied demand shocks $a_{D,t-l} = p^{LIV}_{t-l} + b_D\big(x_{t-k-l} - \Delta s^{LIV}_{t-l}\big)$ with the estimated slope of the demand function from the previous section as an instrument for exports and stock changes in column 3. In column 4 lagged Liverpool prices are again used as an instrument, but here $x_{t-k-l} - \Delta s^{LIV}_{t-l}$ is added as a control, leaving only demand variations in the instrument.

The estimates yield a similar estimate of around 1.8 in all specifications after eliminating measurement error in the OLS estimation. Again, the equivalent supply elasticities are larger than the estimates based on yearly data mentioned in the literature, which are between 1 and 2 (see Irwin 2003 for a review), as is expected when

TABLE 12—ESTIMATION OF THE SLOPE OF THE SUPPLY FUNCTION

Dependent variable: p_t^{NY}	OLS (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)
$\Delta s_t^{NY} + x_t$	0.071	1.862	1.829	1.832	1.585	2.481
	(0.026)	(0.338)	(0.308)	(0.312)	(0.305)	(1.008)
$x_{t-k-l_t} - \Delta s_{t-l_t}^{LIV}$				−0.037	−0.082	0.096
				(0.043)	(0.049)	(0.071)
Observations	554	554	500	500	233	267
Harvest year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Harvest cycle	Yes	Yes	Yes	Yes	Yes	Yes
Instrument		Known Liv. price	Known demand shock	Known Liv. price	Known Liv. price	Known Liv. price
First stage F-stat		46.95	53.95	53.04	45.97	6.21
First stage coefficient		0.269	0.283	0.283	0.325	0.356
		(0.039)	(0.039)	(0.039)	(0.048)	(0.143)
Supply elasticity	410.0	15.7	16.0	15.9	24.7	7.5
Sample	Full sample	Full sample	Full sample	Full sample	Before telegraph	After telegraph

Notes: Prices are denoted in pence/pound. The quantities in the regressor are given in 1,000 bales (1 bale ≈ 400 pounds). Harvest cycle controls for day of the harvest season, and the square of it. HAC standard errors in parentheses.

considering the substitution of supply across short time periods. When repeating the analysis of the supply estimation across data with an increasing aggregation horizon, the supply elasticity falls considerably and converges toward the estimates in the literature (see the online Appendix for details).

Estimation of Efficiency Gains.—Combining the estimates for the slope of the supply and demand functions with the observed price difference according to formula (8) yields an estimated deadweight loss with respect to the perfect-foresight benchmark case for every day in the data. Table 13 reports the aggregate annual deadweight loss before and after the telegraph. The difference in deadweight loss can be attributed to the telegraph and corresponds to around 8 percent of the aggregate annual cotton export value (or 3 percent of total US exports).[40] I construct a confidence interval for the deadweight loss using the delta method on the estimates of the slopes of the supply and demand functions. The confidence interval of the efficiency gains from the telegraph ranges from 4 percent to 13 percent.

Three-quarters of the efficiency gain comes from reducing the variance of the price difference (due to within-year reallocation; mostly across weeks rather than across days within a week), and one-quarter from reducing the average price difference (due to increased average trade). If I exclude the anecdotal episode with the especially large demand shock described earlier from the calculation, the efficiency gain is 7 percent.

What are the sources of these efficiency gains? Why did cotton millers not postpone consumption if prices were high, or use storage to become less dependent on price shocks? In other words, why was the demand of cotton millers not perfectly

[40] Assuming that other US cotton ports experienced a similar efficiency gain as New York, and that there were no efficiency gains in exporting any other products.

Table 13—Estimation of Efficiency Gain from Telegraph

	Annual deadweight loss, pounds	95% confidence interval
Before telegraph	837,703	[394,854; 1,277,383]
After telegraph	109,314	[51,135; 167,477]
Change	−728,389	[−343,719; −1,109,906]
Change in percent	−87	
In percent of export value	−8.4	[−4.0; −12.8]

Note: Confidence interval of deadweight loss calculated using the delta method on estimated slopes of the demand and supply functions.

elastic? First, cotton spinners did not hold much raw cotton stock (Milne 2000; Farnie 1979). As I explain in the online Appendix, about 80 percent of the cotton stock was stored in warehouses near the port by storers, and only 20 percent was held by spinners in widely scattered stocks. This has a number of reasons: cotton is bulky and therefore needs large storage space, which was costly. Storing large quantities of cotton ties up capital, and is therefore costly as well. Liverpool and Lancashire were so well integrated (rapid transportation by railway and fast communication via telegraph), and the Liverpool market was considered so efficient, that it was cheaper for spinners to get their supplies directly from the exchange and have it shipped to their mills when needed, despite the price fluctuations (Farnie 1979). (In contrast, spinners on the continent, which were further away from cotton exchanges, had to carry large reserve stocks in extensive warehouses, requiring more capital and therefore capital cost.) Finally, because cotton is one of the most inflammable raw materials, and fire risk at mills was large, with fireproof mills built only in the 1870s or 1880s, it was better not to store too much cotton at the mill (Shaw 1882; Farnie and Gurr 1998).

Second, the capital cost of constructing a cotton mill (including the machinery) was very high, so the economics included a larger fixed-cost component compared to labor and raw material cost (Farnie 1979; Fogg 1892). Cotton millers wanted to keep the mills running as many hours a week as possible, "[keeping the] machinery steadily and continuously working on orders" (Shaw 1882, p. 27). Cotton millers were very worried about stopping the production process: "any accident or needless stoppage means certain loss." (Fogg 1892, p. 19) This is also reflected in the long working hours of mill workers (72 hours plus overtime) with very few breaks, which was only gradually and reluctantly eased until the end of the nineteenth century.[41] Mill managers even tried to reduce the time for replacing empty spindles with full ones as much as possible, to maximize output. Only when demand or supply was really low did the mills engage in working "short time," i.e., reduce the weekly hours of their workers. Farnie (1979) describes that this happened only a few times during the nineteenth century, and not during the years studied in this paper.

Third, cotton millers faced a very volatile demand for their output of yarn and cloth. They had agents who watched the markets for yarn and cloth daily and advised "the manufacturer of all new demands and all changes in the requirements of the market, that the manufacturer may adapt his production to the varying wants of

[41] See http://www.spinningtheweb.org.uk/people/working.php, Fogg (1892), and Kenworthy (1842).

the world" (Shaw 1882, p. 27). This is because the market for their output was not just the domestic market, but the world market, and unpredictable developments in different countries with varying preferences led to rapid fluctuations because of war, peace, and ceasefire negotiations. In the online Appendix, I show the demand fluctuations for yarn, the output of cotton millers, using a weekly assessment of demand conditions from the *Manchester Times.* While this measure is not perfect, it indicates rapid changes in demand for the millers' output.

The numerical model gives an alternative to assess the efficiency gains from the telegraph, as it allows the estimation of counterfactual scenarios. For example, we can ask how much storage cost would have had to be reduced to achieve the same efficiency gains as those brought by the telegraph. The numerical simulations suggest that the change in information frictions led to an efficiency gain equivalent to a reduction in storage cost of around 20 percent.

VI. Conclusions

This paper exploits a clean historical experiment to assess the impact of information frictions on the law of one price and trade: the establishment of the transatlantic telegraph cable connecting the United States and Great Britain in 1866. This episode provides a unique setting for studying information frictions. On one hand, it provides a dramatic and exogenous reduction in information frictions, as information transmission times fell unexpectedly from around ten days to only one day. On the other hand, I was able to draw upon a rich dataset based on historical newspapers, including high-frequency data not only on prices, but also on trade and information flows.

This setting allows me to contribute to the literature in several ways. First of all, it is possible to *identify* and *measure* the impact of information, which is usually endogenous, complex, and unobserved. This paper shows that a fall in information frictions causes better adherence to the law of one price. The average price difference between New York and Liverpool falls by 35 percent, and its variance falls even more dramatically, by 93 percent. This reduction in price distortions is equivalent to abolishing a roughly 7 percent ad valorem trade tariff.

Second, this paper shows that information frictions have real effects and are not just a reallocation of profits across market participants, because exports *respond* to information. After the telegraph, average trade flows increase and become more volatile. The model explains that this is the case because exports follow expected demand, conditional on information. More information makes expected demand more volatile, which explains why we observe more volatile exports after the telegraph. However, this effect is asymmetric, as there is a threshold beyond which it is not profitable to export at all. More information increases average exports, because there are more incidents with high expected demand and therefore large exports.

The third contribution of the paper lies in estimating the efficiency gains from reducing information frictions. Better information helps merchants to forecast future demand, resulting in a more efficient alignment of supply and demand across countries. This is reflected in the better adherence to the law of one price. To translate the reduced price distortions into efficiency gains, one needs to estimate supply and demand elasticities, which is usually difficult due to simultaneously determined prices and quantities. This paper uses a novel identification strategy that exploits the fact that exports are predetermined once they arrive in Liverpool (since shipping takes time) and controls adequately for the possibility of storage. Overall, the efficiency gains from the telegraph are estimated to be around 8 percent of annual export value.

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