For Online Publication Only: Appendix to Real Effects of Information Frictions

Claudia Steinwender*

MIT

September 25, 2017

1 Introduction

The Online Appendix provides additional background information, robustness checks, analyses, and mathematical proofs. In the interests of clarity some text from the paper is reproduced. The material is organized into sections that have the same numbers and names as in the paper, while figures and tables are provided at the end of the Online Appendix.

2 Historical Setting

2.1 Raw cotton

Cotton accounted for more than one half of US exports in the mid-19th century (Bruchey 1967, see Figure A.1). The term "King Cotton" was coined before the American Civil War and reflected its tremendous importance for 19th-century economies (Surdam 1998). This dominance did not stop after the war: American cotton "was not toppled from his throne" and "resumed his former position of power," as Woodman (1968) phrases it.

In the mid-19th century, cotton was grown primarily in the southern United States (over 55% of world production, Ellison 1886). The second-largest producer was India (29%), followed by Egypt (9%) and Brazil (5%). The dominance of the United States in cotton production is mainly explained by the superior quality of American cotton, whose longer and stronger fibers were preferred by spinners (Irwin 2003; Henderson 1969). Other advantages of American cotton were lower production costs, lower transport costs, and faster shipping.

Cotton millers needed different machinery for spinning American cotton as compared to Indian cotton, therefore in the short run (i.e., less than a year) there was no substitution across different types of cotton. The sharp reduction in the supply of American cotton during the American Civil War (April 1861 to May 1865) led to increased patenting of machinery suitable for spinning Indian cotton (Hanlon 2015). While

*csteinwe@mit.edu, https://sites.google.com/site/clsteinwender/

there was some replacement of American with Indian cotton over the course of the war years, the supply of American cotton during the war remained significant.

2.2 British textile manufacturing

One third of Great Britain's imports was cotton (The Economist 1866, see Figure A.1). Cotton millers spun the raw cotton into yarn, which was then woven into fabrics and sewn into a wide variety of apparel and accessories. The industrial revolution in Great Britain produced several inventions in cotton manufacturing such as the spinning jenny, or the spinning frame, making the country the world's leading textile manufacturer: Great Britain manufactured 85% of cotton goods worldwide and consumed half of the world's cotton production (Ellison 1886). Textile manufacturing was geographically highly concentrated and took place mainly in Lancashire, the hinterland of "Cottonopolis" Manchester.

2.3 Merchants and trade

Virtually all the cotton destined for Great Britain arrived at Liverpool, Lancashire's closest port. On the other side of the Atlantic, New York was the major port exporting to Great Britain: In 1866, 33% of cotton exported to Great Britain was shipped from New York, followed by New Orleans (28%) and Mobile (18%).[1]

Cotton that was not sold to merchants on any given day in New York could either be stored for future exporting or be sold to the domestic cotton millers in New England. New York's cotton exports were predominantly shipped to Liverpool (only 2% of cotton in my data was exported to Le Havre or Bremen).

A thriving mercantile community was responsible for bringing cotton from source to destination. Direct exporting by cotton farmers made up <1% of imports (my own estimation based on a sample of the Bills of Entry generously provided by Graeme Milne and data from historical trade directories). Most merchants were generalists: In the 1860s, only 11-13% specialized in a specific commodity, and 13-14% specialized in certain trade routes (Milne 2000). Merchants were in fact early multinationals: They often set up a subsidiary in important foreign port cities, mostly run by family members (Ellison 1886; Milne 2000; Chapman 1984). Merchant trade was associated with relatively low entry cost, leading to fierce competition.[2] In fact, 100–200 merchants were active in cotton trade between New York and Liverpool in 1866.[3] Merchants were usually not credit constrained, as there was a well-developed and functioning banking sector that provided trade financing (Chapman 1984; Brown 1909).

Organized exchanges for cotton existed in both New York and Liverpool. Merchants bought cotton at the New York exchange from farmers, shipped it to Liverpool, and sold it at the Liverpool exchange to millers. Due to the dominance of Great Britain in textile manufacturing, Liverpool essentially set the world price for cotton.

[1] *Shipping and Commercial List*, printed on 11 October 1866 in *The New York Times*

[2] Milne (2000) notes that in the 1850s and 1860s many people entered the trading profession, and competition was so strong that some traders were willing to work on a no-profit, no-commission basis.

[3] Based on the Bills of Entry and historical trade directories.

2.4 Storage

At each exchange there were also so-called "speculators," who bought cotton when they thought prices would go up, stored it, and sold it at a later time. About 80% of the cotton stock was stored in warehouses near the ports by speculators, while spinners held only some widely scattered stock and stored only as much cotton as they needed to supply their mills in the short run (Milne 2000).

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 farther 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).

2.5 Demand fluctuations

When merchants bought their cotton at the New York exchange, they had to forecast demand conditions in Liverpool upon its arrival. Demand for cotton at the exchange in Liverpool originated from cotton millers. 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 the world." (Shaw, 1882). This is because the market for their output was not just the domestic market, but the world market, and impredictable developments in different countries with varying preferences led to rapid fluctuations because of war, peace, and ceasefire negotiations. Market reports in historical newspapers describe how 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. When a country was at war or under threat of war, its demand for cotton textiles dropped considerably, as the country shifted its funds towards expenditures such as arms and munitions. The Austro-Prussian war and the threat of a Franco-Prussian war fall within my sample period, and newspapers frequently identified changes in war conditions as reasons for rising or falling demand from cotton millers. The outlook often changed within days, e.g., when ceasefire negotiations were begun or abandoned.

To demonstrate this, consider the output of cotton millers, yarn. Yarn is mostly sold at the Manchester yarn market, for which the *Manchester Times* provided a weekly assessment of demand conditions. I coded these demand conditions and show their volatility over time in Figure A.2 below. Yarn demand fluctuates at quite high frequency; weeks of "animated" demand suddenly switch to "depressed" demand. Of course this assessment is not a perfect measure of demand volatility, but it should be a better measure than price volatility, which depends on both both supply and demand volatilities, and gives an indication of the frequency of fluctuations.

2.6 Information at the exchange

Information was important at the cotton exchanges. The 19th-century equivalent to computer screens with price tickers was a large billboard with the latest price information and news, together with newspapers and circulars that summarized market developments, available in the Exchange Newsroom. The news agency Reuters provided a subscription service with the most important news from all over the world. The compilation of news included the cotton prices from New York and Liverpool and was called *Reuter's Telegram* – even before the transatlantic cable was established, because the news traveled overland via telegraph. Newspapers as well as the cotton exchanges were subscribers. Since *Reuter's Telegram* was posted publicly at the exchange, individual merchants could get it at zero cost, and it was therefore public information from the point of view of merchants (Farnie, 2004).

2.7 Steam ship travel time

The first successful transatlantic telegraph connection between Great Britain and the United States was established on 28 July 1866 and dramatically reduced the delay in information transmission across the Atlantic. Before the telegraph connection, the only means of communication across the Atlantic was by sending letters and messages (including copies of *Reuter's Telegram*) via steam ships. The so-called "mail steam ships" were the fastest of their day, specializing in speedy transmission of information items such as letters, newspapers, and other documents. There was fierce competition among mail steam ships to win the unofficial "Blue Riband" for record speeds, and by 1866 the fastest ship had crossed the Atlantic in a little over eight days (Gibbs 1957). However, such speeds could be achieved only under the best weather conditions; in practice there was great variation in communication times. If conditions were very bad, ships could take as long as three weeks to cross the Atlantic. Important commercial information was transmitted between the commercial hubs in the United States and Great Britain using a combination of existing land-based telegraph cables and mail steam ships. For example, the Liverpool price of cotton was telegraphed from Liverpool via the submarine Ireland/Great Britain connection to a steam ship passing the coast of Ireland on its way to the United States. As soon as this ship reached the first telegraph post on the US coast, this information was further telegraphed to New York by land line, arriving before the steam ship itself.

2.8 History of establishment of the transatlantic telegraph

The transatlantic telegraph connection changed communication flows dramatically and immediately. For the first time in history, information traveled faster than goods across the Atlantic (Lew and Cater, 2006). Suddenly, communication between the United States and Great Britain was possible within only one day. There were occasional technical breakdowns of the telegraph connection, but these were usually repaired within a couple of days.

The timing of the successful telegraph connection was unforeseen and exogenous to economic conditions, because the process was characterized by a series of failures and setbacks over the course of around ten years, greatly eroding confidence in its feasibility. These technical difficulties arose because the transatlantic cable had to traverse a greater distance (3,000 km; 1,800 mi) at a greater submarine depth (3,000 m; 9,800 ft) than any previous telegraph connection. Previous submarine cables, e.g., those connecting Great Britain to Ireland and France, were much shorter and lay much shallower. Consequently, it took five attempts over almost a decade before a lasting connection was established on 28 July 1866 (Clarke 1992 provides a detailed and entertaining history of the cumbersome way towards a transatlantic connection.). 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 with transmission speed too slow for commercial purposes: The first message took 17 hours to transmit, and the average transmission speed was 0.1 words per minute. The sent messages contained questions about how to increase speed and requests for re-sending poorly transmitted messages, but no commercial news (Clarke, 1992). In any case, the connection lasted only briefly. After three weeks, the insulation of the cable was damaged, and the connection broke down permanently. After this failure, the public lost faith in the telegraph project, and another attempt scheduled for the same year was delayed indefinitely. In fact, confidence in the technology had become so poor that the media suspected the working connection had been a hoax altogether. The *Boston Courier* asked: "Was the Atlantic Cable a Humbug?"

Although technical understanding of undersea electrical signal transmission had progressed, the fourth attempt in 1865 again resulted in a broken cable with ends lost in the ocean. By 1866 there was little confidence left. 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 28 July 1866 the first telegraph message, a congratulatory message from the Queen of England to the President of the United States, was transmitted. From then on, the telegraph worked quickly and surprisingly reliably. The newspapers of the next working day already reported cotton prices from the other side of the Atlantic in their commercial sections. By early September, the 1865 cable was pulled out of the sea and repaired. The two working transatlantic connections provided fast and reliable transatlantic communication. The transatlantic cable came to be referred to as the "Eighth Wonder of the World," reflecting people's amazement about this technological milestone.

3 Data description

3.1 Common pitfalls when studying the Law of One Price

Many observed "violations" of the Law of One Price can be blamed on a lax interpretation of requiring an identical good traded at different locations (Pippenger and Phillips 2008). For example, wheat grown in the United States and wheat grown in Great Britain are not identical, and even different varieties of wheat grown in the United States are not identical. This is a severe restriction on the data, as many local newspapers – the primary source of historical market information – report prices of the local variety and not foreign varieties. Sometimes, for example for wheat, they report prices on foreign varieties, but then not for the same variety over a consistent period of time. For example, the *Aberdeen Journal* reported weekly American winter and American spring prices for the London market but stopped in July 1866 for no apparent reason; *The Economist* and *The Daily Courier* made similar reports for American and Canadian Red Wheat. In contrast, *The Daily Courier* started to report Chicago wheat prices only in August 1866. Some newspapers reported weekly wheat prices for some American varieties over longer time series, but the prices show no variation, which means there was no underlying trade based on the commodity, and prices were simply copied forward at the same level for months. Ejrnæs and Persson (2010), who also fail to find grain price data for the years around 1866, explain that the export of US grain ceased temporarily during these years.

Another pitfall when studying the Law of One Price is using retail instead of wholesale prices. Thus it is better to have data on a good that is traded on organized exchanges (as here) rather than local farmers' markets.

In any case, using weekly data decreases the power of tests relating prices to news, and observed time periods for consistent varieties (e.g., of wheat) are not long enough to compensate (usually after 2–3 years the reported varieties change).

3.2 Data collection

Data were collected from two historical newspapers: The *Liverpool Mercury* was accessed via the 19th-century British Library newspaper collection published by Gale group. *The New York Times* was accessed via ProQuest Historical Newspapers.

The resulting data set combines four types of data: market information from the Liverpool exchange, market information from the New York exchange, trade flows between New York and Liverpool, and information flows between New York and Liverpool.

Market information from the Liverpool exchange was reported in the *Liverpool Mercury*, whose daily section called "Commercial" provided a detailed market report on cotton. The *Liverpool Mercury* published the daily price for "middling American," where "middling" indicates a specific quality of American cotton. Cotton was graded into around seven different qualities (three above and three below middling): "ordinary," "good ordinary," "low middling," *"middling,"* "strict middling," "good middling," "middling fair" (ordered from lowest to highest quality). Middling was the variety with the largest trade volume and was used as the main reference category. Qualities besides middling were not consistently reported in the newspapers, but a reprint from a Cotton Circular gives an indication on how different these qualities were (see Table B.12): While there was quite a large difference between cotton of the highest (14% higher than middling) and lowest quality (19% lower than middling), the middling category is quite narrow (cotton with 4% higher and lower prices are already in different categories).

Market information from the New York exchange was reported in *The New York Times*, which also published a daily commercial section with detailed information on cotton. Again, the prices reported there are for middling American cotton. Several market reports pointed out that New York used the same classification scheme as Liverpool, as this was the most important destination for cotton.

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*. The fluctuations in exchange rates were very small (note that Great Britain, but not the US, had adopted the gold standard, so there was no fixed exchange rate). Using the average exchange rate for the whole period as opposed to the daily exchange rates does not affect my results.

Figure A.3 illustrates the resulting time series of daily New York and Liverpool cotton prices. The Liverpool price for cotton almost always exceeded the New York price, except for a short period in May 1866. By and large, the price series seem to move in parallel.

I can also reconstruct the data on information flows from newspapers, as both the *Liverpool Mercury* and *The New York Times* reported the latest mail ship and telegraph arrivals on any given day and printed the main commercial indicators from the other country that these shipped or telegraphed messages included. The relevant sections were headed "Latest and Telegraphic News" (*Liverpool Mercury*) and "News from Europe" (*The New York Times*). These indicators included certain bond and stock prices and the price of cotton. 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 dates yields the information transmission time across the Atlantic for any given day, which I call "information delay l_t". Figure A.4 shows the information lag over time. The transmission times in my data correspond to the fastest mode of communication between Liverpool and New York, rather than corresponding steam ship travel times. The difference arises because steam ships often received the latest commercial news from England via telegraph while passing the last part of the Irish Coast; upon arrival on the Newfoundland Coast the news was again transmitted via telegraph to New York, arriving before the ship itself. Sometimes steam ships were overtaken by other, faster steam ships, rendering the slower ship's news "old." In that case the newspapers reported "news was anticipated."

My final database comprises 604 observations, one for every work day between 29 July 1865 and 27 July 1867. The cotton exchange was open every week Monday through Saturday, except on holidays and a few other special occasions (for example, during a "visit of the Prince and Princess of Wales"). I discarded days that were holidays only in the UK or only in the US. The resulting time period encompasses one calendar year before (301 work days) and one calendar year after (304 work days) the telegraph connection.

Freight and other transport costs

Cotton could be shipped either using slow sailing ships (taking 1–2 months) or the faster steam ships (2–4 weeks). *The New York Times* had a separate "Freights" section, which reported daily the freight cost paid for each shipment, with information regarding whether the shipment went by sailing ship or steam ship (some days report both). In the regressions I use an average freight rate, i.e., the average of freight cost by sailing ship and steam ship if both are available, or sailing freight rates if only those were reported, or steam freight rates if only those were reported. On some days freight rates are missing, and I use interpolated freight rates for the regression. The results are robust to using only sailing-ship rates, only steam-ship rates, or dropping interpolated freight rates.

Lew and Cater (2006) argue that the telegraph reduced freight rates by increasing the capacity utilization of shipping, so the observed drop in freight cost could in principle be attributed to the telegraph. However, it is likely that this effect materialized only after a couple of years (Lew and Cater 2006 used data from the 1870s) and not immediately, so in order to be conservative I do not attribute this reduction to the telegraph.

While freight cost accounted for the major part of total transport costs, there were others. Boyle (1934) provides a detailed account of all other transport costs, using historical bookkeeping figures of merchants. Table B.1 contains a detailed breakdown of total transport costs. The vast majority, 83.1%, are charged based on weight, so they were unit costs. Freight costs are the most important component of unit transport costs, comprising 65% of total transport costs. The remaining unit transport costs are paid for handling at the ports (e.g., bagging, marking, wharfage, cartage, dock dues, weighing, storage). Ad valorem transport costs constitute 16.9% of total transport costs and include fire and marine insurance, Liverpool town dues, and brokerage. I calculated ad valorem transport cost to be 16.9% of the daily New York price to obtain an estimate of daily ad valorem transport cost. There was no duty on cotton in transatlantic trade during the time period used in this paper (Chilosi and Federico, 2015).

Cotton stock in Liverpool

The *Liverpool Mercury* provided weekly estimates of the stock of cotton in Liverpool warehouses, separately for the categories: "American," "Egyptian, &c," and "E. India." The stock data are estimates, and stock is fully counted only at the end of each quarter. Since these error corrections do not reflect actual changes in stock, I disregard stock information at the end of each quarter. I distribute the weekly stock changes evenly across the days of the work week for regressions that use daily observations.

Cotton stock in New York

The New York Times reported weekly and later bi-weekly estimates of the stock of cotton in New York warehouses. I distribute the weekly and bi-weekly stock changes evenly across the days of the work week between stock takings for regressions that use daily observations.

Cotton receipts in New York

The New York Times reported the daily receipts of cotton that arrived at the exchange from farms that day via overland routes or Southern ports. While *The New York Times* reports only total receipts, the weekly newspaper *The Commercial & Financial Chronicle* reported cotton receipts in New York by their origin, i.e., New Orleans, Texas, Mobile, Savannah, South Carolina, North Carolina, Norfolk, and Baltimore, and an extra category "Per Railroad" for the overland shipments.

4 Reduced-Form Findings

Additional figures and tables that provide robustness checks mentioned in the paper can be found at the end of the Online Appendix in the corresponding section.

4.1 Standard errors

Unless otherwise indicated, all tables use Newey West standard errors to account for potential autocorrelation and heteroskedasticity in the error terms of the regression model. The autocorrelation order of the error terms was determined by examining the correlogram of the error term and selecting the lag by which the partial autocorrelation had faded out (i.e., approached the 95% confidence band around 0).

4.2 The American Civil War and the cotton harvest cycle

During the Civil War, the Northern states (the "Union") established a blockade of the Confederate States' ports that stopped cotton exports almost completely. After the war, cotton production and trade were immediately taken up again: Woodman (1968) describes how the reopening of trade with the South immediately induced a "scramble among cotton merchants." However, it took five to 10 years before pre-war cotton production was restored. Reasons for the slow recovery included the destruction of cotton during the war, the substitution of cotton production for food production, the bankruptcy of many cotton planters, and the abolishment of slavery (Woodman 1968); see Figure A.7 for the full time series.

Figure A.8 illustrates the time pattern of cotton supply over the course of a harvest year. The growing cycle starts between February and June, depending on the geographic area (cotton was grown in a large area, stretching across 17 states). The harvest season begins in July in the southern areas and in late November in more northern areas. Cotton harvesting was manual, very labor intensive (mechanization of picking started only after the Second World War) and took several weeks for each farm. Overall, cotton harvesting took place over a period of approximately six months. After harvesting, the cotton had to be shipped to the exchange in New York and other ports. This was again a very time-consuming process (due to the long distances, capacity constraints on railways, as well as droughts and floods of rivers used for shipping), such that from the point of view of the New York exchange, cotton was supplied throughout the year (Bruchey, 1967; Hammond, 1897).

This is visible in the daily cotton receipts at the New York exchange, shown in Figure A.8 in this Online Appendix. The Figure reflects the general harvest cycle: More cotton is received between September and April, less between May and August. However, due to the time-consuming picking process and the long distances between the cotton fields in the interior of the US to New York, the supply of cotton is positive on every day except one day in the sample. The visual evidence does not suggest that the variation in cotton supply differs very much from before to after the telegraph. There is one spike in the pre-telegraph data, but this is an artifact of the data, as it is due to the closure of the New York cotton exchange over two Christmas holidays, when arrivals had piled up.

4.3 Futures and forward trading

Transatlantic cotton futures trading developed gradually over the course of the 19th century (Dumbell, 1927; Irwin, 1954; Ellison, 1886; Hammond, 1897). While cotton traveled across the Atlantic as fast as news or information, forward trades were not possible, because contracts between merchants on either side of the Atlantic could not be negotiated faster than sending the actual consignment of cotton. When fast, specialized mail steam ships came, forward contracts (often called business "to arrive" or "in transit") started to appear: The fast mail steam ships would carry letters and samples, allowing the slower cargo to be sold while still at sea. The telegraph greatly increased the difference between information travel time and shipping time of cotton, and made futures trading possible. However, it took a couple of years for merchants to understand this potential: The "invention" of the first transatlantic futures trading (including short selling and therefore its use for hedging) is usually dated to 1868 or 1869 (Woodman, 1968), and took off fully only when organized futures trading at the exchanges was developed in the 1870s. New York, Liverpool, and New Orleans were the first cotton exchanges with organized futures trading, and the rules for futures were gradually refined and extended (e.g., standardized contracts, rules defining specific cotton qualities, rules for down payments and financial settlements and rules for the legal enforcement). All of this happened after my sample period.

In my model, it is interesting to note that a problem with speculators engaging in futures trading leads to the same market-level equilibrium conditions as a model with explicit modeling of storage, as long as at least some speculators have rational expectations and are risk neutral. Given a mix of stock holders and speculators, and stock holders are not risk neutral, as long as some speculators are risk neutral and have rational expectations, these equilibrium conditions for the market still hold. Expected prices in the first-order conditions for merchants and storers are equivalent to the prices of futures. While futures trading might lead to a different allocation of risk across market participants (from risk averse to less risk averse or risk neutral), the aggregate properties of a model with storage and one with futures trading are the same (Williams and Wright 1991, p. 28).

4.4 Re-routing of shipments from southern ports to New York

Is it possible that we see increased exports because the telegraph caused cotton suppliers to re-route shipments from Southern ports through New York? Let me first point out that if the increase of exports from New York is only because shipments had been re-routed from the South through New York, this would *not* show up as an increase in exports once cotton receipts in New York are controlled for, because the cotton receipts *do include* shipments from Southern ports to New York and would therefore capture this increase (see data description).

While this therefore shows that the exports from New York are over and above what is due to possible re-routing of shipments from Southern Ports (and would have gone to domestic production in New England otherwise), I collected data on aggregate world exports from the US and from the second most important port, New Orleans, for additional robustness checks from the weekly newspaper *The Commercial & Financial Chronicle*. However, I was not able to find these data at daily frequency, only weekly. Furthermore, these data started to be reported only after 14 April 1866, and only very sporadically before that date. In order to make sure seasonality does not affect the comparison before and after the telegraph (by comparing different weeks of the harvest year to one another), I use only data from the same weeks of the year in the after-telegraph period for comparison (so I compare the same weeks in the harvest cycle across years).

Tables B.7 and B.8 in this Online Appendix replicate the regressions in Table 8 of the paper on this new weekly dataset. The controls are the same as in Table 8, i.e., they refer to transport cost from New York and cotton receipts at the New York exchange (just aggregated to the weekly level by using means for transport cost and sum for cotton receipts). The dependent variables are world exports from New Orleans in Table B.7 and world exports from all ports of the United States in Table B.8. The tables show that the telegraph has a positive effect on both exports from New Orleans and total US exports. This shows that the telegraph caused increases in exports that are not simply driven by re-routing.

4.5 Herfindahl index

Bills of Trade record the shipment of every merchant arriving in Liverpool and allow for the computation of a Herfindahl index. The Bills of Trade have been digitized for three months (February, June, October) of four years around the time of the introduction of the telegraph (1855, 1863, 1866, and 1870). Figure A.9 shows the development of the Herfindahl index for cotton merchants, separating shipments from the US from shipments originating in Egypt and the East Indies. In 1863 the American Civil War disrupted cotton trade, and only a few cotton shipments came from the US to Great Britain: the Herfindahl index shows high concentration. However, after the Civil War the Herfindahl index immediately returned to a very small number (around 0.05), indicating a very competitive market structure, and remained so until the 1870s. The market structure of merchants shipping from the East has a similar Herfindahl index, though without the disruption of the Civil War.

4.6 Banking crisis in May 1866

Can the increased volatility of exports be explained by the banking crisis of May 1866 that was started by the bankruptcy of the discount house Overend Gurney rather than the telegraph? To empirically test this concern, I added a dummy variable called "banking crisis" to the regressions on the volatility of exports (Table 9 in the paper), which takes the value of 1 for the duration of the crisis, and 0 otherwise. The banking crisis started when the discount house Overend Gurney suspended payments on May 10, 1866 (Bank of England, 2016). As a response, the Bank of England raised its discount rate from 6% to 10% within just 10 days. Also, the government suspended the Bank of England Act in Parliament, which allowed the Bank of England to extend liquidity without having to back it up with gold. The Bank of England did not end up having to issue unbacked notes, because the policies had the desired effect and restored confidence in the money market. According to the Bank of England, as assessed in retrospect (Bank of England 2016), this all ensured that "the crisis remained mainly financial in character" and did not affect the real economy. The Bank of England kept the discount rate up until August, but then in a series of reductions, returned it to the pre-crisis level of 6% by August 30, 1866.

The results that contrast the effect of the telegraph with that of the banking crisis are reported in Table B.9 of this Online Appendix. They show that the increase in volatility of exports was not driven by the banking crisis, which started a few months before the telegraph connection. Instead, the effect started only after the telegraph connection became established. (In fact, some specifications even suggests that the volatility of exports decreased after the banking crisis). Controlling for the banking crisis leaves the effect of the telegraph almost unaffected, so the banking crisis should not have been a confounding factor. Note that this finding is consistent with both the assessment of the Bank of England (2016) that the effects of the crisis did not spill over to the real economy, but also with the assessments I found in contemporaneous newspapers ("That crisis has been justly described as financial and monetary rather than commercial"; "our readers will not fail to observe how very little the fluctuations of trade, production, and manufacture have had to do with the financial panic of the year, and how distinct the line of the merchant, the manufacturer, or other producer is from that of the speculator in money and 'finance'" in *The Times*, 8 January 1867 in a review of the trade in 1866).

5 Model of Information Frictions in International Trade

5.1 Numerical solution approach

The central task of the problem is the numerical solution of the control function for storage as a function of state variables. In the instantaneous information case, there are two state variables: "Stock on hand" m_t is the stock available at the beginning of each period, which consists of the sum of quantities stored in the previous period and arriving imports (equal to *NY*'s exports from the previous period), $m_t = s_{t-1} + x_{t-1}$;

and the current realization of the demand shock, a_{Dt}. I approximate $s(a_{Dt}, m_t)$ over a grid of state variables by checking the first-order condition of storers for a guess for the control function and by updating the guess in every step. The approximation algorithm has converged when all the first-order conditions in all grid points are satisfied up to a certain precision. Plugging this solution function into the analytical expression for exports results in a solution function for exports as a function of state variables $x(a_{Dt}, m_t)$.

The delayed information regime requires a different set-up of the problem, as storage and exports are determined by different agents with different information sets. In the delayed-information regime merchants know only lagged demand shocks, so exports are a function of lagged demand and contemporaneous stock on hand (because this itself is a function of lagged storage and exports): $x(a_{D,t-1}, m_t)$. On the other hand, storage in Liverpool continues to be a function of contemporaneous demand, $s(a_{Dt}, m_t)$. Plugging the storage function into the analytical expression for exports then requires a numerical calculation of expected storage in both the current and subsequent periods. I calculate these expectations numerically over the grid points using the respective transition probability matrices. Note that in the delayed-information regime the number of state variables increases to three: a_{Dt}, $a_{D,t-1}$, and m_t.

As the number of calculations needed increases exponentially with the number of state variables (Williams and Wright 1991, p. 57), it is not possible to numerically solve a daily representation of the model. In this case the information lag would be around 10 days, and I would need to keep track of 10 more state variables (or 20 when allowing for supply shocks), which is not computationally feasible. A similar computational limitation appears when current shocks are supposed to depend on a larger number of orders of lagged shocks.

The storage literature gives several different transversality conditions that one can impose to guarantee existence and uniqueness of the equilibrium (Williams and Wright (1991, p. 65), Deaton and Laroque (1996)). Assuming linear demand and supply functions that implicitly invoke a finite "choke price" as in this paper is one such condition.

5.2 Parameter calibration

The solution depends on the following parameters: mean, autocorrelation and variance of the demand process, slopes of the demand and supply functions, and transport and storage cost. In the section on the estimation of the efficiency gain in the paper I describe in detail how I estimate the slopes of the supply and demand functions for a more realistic daily version of the model. For this section I use the same estimation approach on data aggregated over 10-day periods, to maintain consistency with the model. I estimate the mean, autocorrelation, and variance of the shock process from the residuals of the demand function using data from before the telegraph. The estimated AR(1) process fits the data well; it is not possible to reject white noise of the innovations (using a Portmanteau white-noise test). I use average transport cost from the data I described earlier. Data on storage cost are also obtained from the historical accounting statements of merchants (Boyle 1934; Entz 1841) and include storage rates, interest on capital, and waste.

Note that the assumed storage costs are unfortunately not as reliable as the other data, because they are from a single merchant from the 1840s (later data were not available to the best of my knowledge). However, there is another way to calibrate storage cost, using the ratio of stock to exports: In the data, stock was on average worth 60 days of imports (or 6 ten-day periods). According to the model, this level of stock is more consistent with higher storage cost of around 0.25. It is plausible that actual storage cost might have been larger than that reported in the historical merchant accounting statements, which do not account for depreciation or storage capacity constraints. Depreciation of cotton might have been high, as there is evidence that spinners strongly preferred cotton from the current harvest over that from the previous harvest, because the quality of cotton deteriorates over time due to humidity. Warehouse capacity constraints could also have been important: Cotton is very bulky and takes up a lot of storage space, potentially exceeding the available space in warehouses at the docks in Liverpool.

In an extension I also allow for stochastic supply. The estimation of the parameters of the supply process is analogous to the estimation of the demand process. Table B.14 shows the parameters used for calibration. I use the counterfactual instantaneous information regime on the calibrated model to predict the effect of the telegraph on the data.

5.3 No storage

Figure A.12 shows impulse response functions to a demand shock. Under delayed information (before the telegraph, green line), 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* 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 upwards, 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 until the price difference goes back to zero.

Under instantaneous information (after the telegraph, blue line), 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. Note that the dotted line shows the price had merchants been able to foresee the demand shock: Prices in *LIV* would still have risen, as due to the elastic supply in *NY* it is not optimal to increase exports enough to fully smooth out the demand shock. However, because of the shipping delay, prices in *LIV* rise more than that even if there is instantaneous information. 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. Note that in the last figure in Figure A.12 the spikes in the shipping time-adjusted price difference in both the delayed and instantaneous information regimes have the same magnitude. However, this is true only with impulse response functions. If I simulate the model with white-noise innovations, the spikes in the price difference are larger in the delayed- compared to the instantaneous-information regime, as current and lagged shocks overlap.

5.4 Proof of Lemma 1

If the demand shock is AR(1), the variances are:

$$Var\left[E\left[a_{D,t+1}|\, I_{t-1}^{M}\right]\right] = \rho_D^4 Var\left[a_{D,t-1}\right]$$

$$Var\left[E\left[a_{D,t+1}|\, I_{t}^{M}\right]\right] = \rho_D^2 Var\left[a_{Dt}\right]$$

Note that for a stationary AR(1) process, $Var[a_{Dt}] = Var[a_{D,t-1}]$. For $0 < \rho < 1$, $Var\left[E\left[a_{D,t+1} | I^M_{t-1}\right]\right] < Var\left[E\left[a_{D,t+1} | I^M_t\right]\right]$.

□

5.5 Proof of Lemma 2

Consider the analytical expression for exports, and consider first uncensored exports $\tilde{x}_t := \frac{E[a_{D,t+1}] - \bar{a}_S - \tau}{b_S + b_D}$. Uncensored exports in both regimes differ only in the way expectations about future demand shocks are formed. In the instantaneous-information regime the information set includes everything up to period t, while the information set in the delayed-information regime includes only information up to period $t-1$. By the Law of Iterated Expectations, average uncensored exports are the same in both regimes:

$$E\left[\tilde{x}^{DI}_t\right] = E\left[\frac{E\left[a_{D,t+1} | I^M_{t-1}\right] - \bar{a}_S - \tau}{b_S + b_D}\right] = \frac{\bar{a}_D - \bar{a}_S - \tau}{b_S + b_D} = E\left[\frac{E\left[a_{D,t+1} | I^M_t\right] - \bar{a}_S - \tau}{b_S + b_D}\right] = E\left[\tilde{x}^{II}_t\right]$$

The variance of uncensored exports is a function of the variance of expected demand shocks, conditional on the respective information set:

$$Var\left[\tilde{x}^{DI}_t\right] = \frac{Var\left[E\left[a_{D,t+1} | I^M_{t-1}\right]\right]}{(b_S + b_D)^2}$$

$$Var\left[\tilde{x}^{II}_t\right] = \frac{Var\left[E\left[a_{D,t+1} | I^M_t\right]\right]}{(b_S + b_D)^2}$$

and, using Lemma 1, $Var\left[\tilde{x}^{DI}_t\right] < Var\left[\tilde{x}^{II}_t\right]$.[4]

Uncensored exports have the same mean in both information regimes, but the variance of uncensored exports is smaller in the delayed-information regime: $\tilde{x}^{II}_t \sim N\left(\frac{\bar{a}_D - \bar{a}_S - \tau}{b_S + b_D}, \frac{Var(E_t[a_{Dt}])}{(b_S + b_D)^2}\right)$ and

[4]The weak inequality holds irrespective of the demand process. To see this, apply Jensen's inequality to the function $E_t\left[a_{D,t+1}\right]$, conditional on information in *t-1*:

$$\left(E_{t-1}\left[E_t\left[a_{D,t+1}\right]\right]\right)^2 \leqslant E_{t-1}\left[\left(E_t\left[a_{D,t+1}\right]\right)^2\right]$$

Taking the unconditional expectation:

$$E\left[\left(E_{t-1}\left[a_{D,t+1}\right]\right)^2\right] \leqslant E\left[\left(E_t\left[a_{D,t+1}\right]\right)^2\right]$$

The variance of the conditional expectations are:

$$\begin{aligned} Var\left[E_{t-1}\left[a_{D,t+1}\right]\right] &= E\left[\left(E_{t-1}\left[a_{D,t+1}\right]\right)^2\right] - \left(E\left[E_{t-1}\left[a_{D,t+1}\right]\right]\right)^2 \\ &= E\left[\left(E_{t-1}\left[a_{D,t+1}\right]\right)^2\right] - \left(E\left[a_{D,t+1}\right]\right)^2 \end{aligned}$$

$$\begin{aligned} Var\left[E_t\left[a_{D,t+1}\right]\right] &= E\left[\left(E_t\left[a_{D,t+1}\right]\right)^2\right] - \left(E\left[E_t\left[a_{D,t+1}\right]\right]\right)^2 \\ &= E\left[\left(E_t\left[a_{D,t+1}\right]\right)^2\right] - \left(E\left[a_{D,t+1}\right]\right)^2 \end{aligned}$$

Combining the last three equations shows that the variance of a conditional expected value increases if the information set increases: $Var\left[E_{t-1}\left[a_{D,t+1}\right]\right] \leqslant Var\left[E_t\left[a_{D,t+1}\right]\right]$. It follows that $Var\left[\tilde{x}^{DI}_t\right] \leqslant Var\left[\tilde{x}^{II}_t\right]$.

$\tilde{x}_t^{DI} \sim N\left(\frac{\bar{a}_D-\bar{a}_S-\tau}{b_S+b_D}, \frac{Var(E_{t-1}[a_{Dt}])}{(b_S+b_D)^2}\right)$. Denoting $\tilde{\mu} := E[\tilde{x}_t]$ and $\tilde{\sigma}^2 := Var[\tilde{x}_t]$, average censored exports are given by $E[x_t] = \Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\tilde{\mu} + \tilde{\sigma}\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)$ (Greene 2003). A change from *DI* to *II* increases the variance of censored exports $\tilde{\sigma}^2$, and this increases average censored exports x_t:

$$\begin{aligned}
\frac{\partial E[x_t]}{\partial \tilde{\sigma}} &= \phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\cdot\left(-\frac{\tilde{\mu}}{\tilde{\sigma}^2}\right)\cdot\tilde{\mu} + \phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right) + \tilde{\sigma}\phi'\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\left(-\frac{\tilde{\mu}}{\tilde{\sigma}^2}\right) \\
&= \phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right) > 0
\end{aligned}$$

Truncated exports, i.e., average exports conditional on being positive, $E[x_t|\, x_t > 0] = \tilde{\mu} + \tilde{\sigma}\frac{\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)}{\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)}$ also increase when switching from *DI* to *II*:

$$\begin{aligned}
\frac{\partial E[x_t|\, x_t > 0]}{\partial \tilde{\sigma}} &= \frac{\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)}{\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)} + \tilde{\sigma}\left(\frac{\phi'\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\left(-\frac{\tilde{\mu}}{\tilde{\sigma}^2}\right)\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right) - \phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\cdot\left(-\frac{\tilde{\mu}}{\tilde{\sigma}^2}\right)}{\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)^2}\right) \\
&= \frac{\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)}{\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)} + \tilde{\sigma}\left(\frac{\frac{\tilde{\mu}^2}{\tilde{\sigma}^3}\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right) + \phi^2\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)\frac{\tilde{\mu}}{\tilde{\sigma}^2}}{\Phi\left(\frac{\tilde{\mu}}{\tilde{\sigma}}\right)^2}\right) > 0
\end{aligned}$$

if $\tilde{\mu} > 0$, which is assumed for exports to be positive on the average realization of the demand shock.

Note that this proof also holds if there are stochastic supply shocks. Since merchants are in *NY*, there will be no uncertainty about the realization of supply shocks, so information is not relevant. Supply shocks are relevant only when storage is allowed.

□

5.6 Proof of Lemma 3

The variance of the forecast error under the *II* regime (note this is the same whether conditioning on positive exports or not),

$$Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_t^M\right]\right] = Var[\epsilon_{D,t+1}] = \sigma_D^2 = Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_t^M\right]\Big|\, x_t^{II} > 0\right]$$

while under the *DI* regime,

$$Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_{t-1}^M\right]\right] = Var[\epsilon_{D,t+1} + \rho_D\epsilon_{Dt}] = \left(1+\rho_D^2\right)\sigma_D^2 = Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_{t-1}^M\right]\Big|\, x_t^{DI} > 0\right]$$

from which follows

$$Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_{t-1}^M\right]\right] > Var\left[a_{D,t+1} - E\left[a_{D,t+1}|\, I_t^M\right]\right]$$

for $0 < \rho$. Note that this result also holds strictly for random walk shock processes.

□

5.7 Storage

Figure A.13 illustrates the effect of information in a model with storage. Consider first the instantaneous information case, i.e., the blue line. As a demand shock hits, exports increase, but because of the shipping delay this affects *LIV* prices only in the next period. However, stock can be released from storage to satisfy the demand. This reduces the impact of the demand shock on *LIV* prices quantitatively, but not enough stock is released to smooth prices in *LIV* perfectly.

Because storage does not fully smooth prices, there is still a spike in the price difference adjusted for shipping time. During the next period, the increased exports arrive, but the *LIV* price does not fall very much, as demand is still high. Stock no longer has to be run down as much in order to stabilize the price in *LIV*. The IRFs show that 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, over which stock is slowly built up again.

With delayed information (green line), equilibrium stock is higher. When a demand shock hits, stock is released just as in the instantaneous-information 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.

5.8 Supply shocks

With supply shocks, the unknown control function for exports becomes $x\left(a_{St}, a_{Dt}, m_t\right)$ in the *II* regime and $x\left(a_{St}, a_{D,t-1}, m_t\right)$ in the *DI* regime. Storage in *LIV* depends on the information about supply shocks: $s\left(a_{St}, a_{Dt}, m_t\right)$ in the *II* regime, and $s\left(a_{S,t-1}, a_{Dt}, m_t\right)$ in the *DI* regime. The number of state variables in the *DI* regime increases to five: a_{Dt}, $a_{D,t-1}$, a_{St}, $a_{S,t-1}$ and m_t.

5.9 Risk aversion

Risk aversion is added to the model in a stylized, simplified way by adding a constant risk premium of 0.91 (equivalent to the change in the average price difference) to the model with the delayed-information regime to illustrate that a reduction in the risk premium has the potential to magnify the effects of the telegraph.

6 Efficiency Gains from the Telegraph

6.1 Derivation of welfare, equation 6.1

Welfare is given by:

$$W_t := PS_t + CS_t + MS_t + SS_t + ESS\left(s_t\right)$$

The inverse market-demand curve is given by demand by both consumers and storers, $p^M(q) = a_{Dt} - b_D q + f(q, a_{Dt})$.[5] The sum of consumer surplus and expected surplus from storage is therefore given by the area underneath the market-demand curve, minus the price paid by consumers and storers:

$$CS_t + ESS(s_t) = \int_0^{c_t+s_t} p^M(q)dq - p_t^{LIV}(c_t + s_t)$$

Current consumption and storage equals current imports and past storage, $c_t + s_t = x_{t-1} + s_{t-1}$. The immediate producer surplus is given by the area above the supply curve up to the price received by producers when selling to merchants in NY.[6] For ease of notation, because of the shipping time, I denote current producer surplus as the surplus coming from the imports arriving in the current period and produced in the period before:

$$PS_t = p_{t-1}^{NY} x_{t-1} - \int_0^{x_{t-1}} p^S(q)dq$$

Note that I allow for supply to be stochastic. The surplus of merchants is given by their profits (or losses):[7]

$$MS_t = \left(p_t^{LIV} - p_{t-1}^{NY}\right) x_{t-1}$$

The surplus (or losses) of storers from selling the stock they had at the beginning of the period is given by:

$$SS_t = \left(p_t^{LIV} - p_{t-1}^{LIV}\right) s_{t-1}$$

6.2 Proof of Theorem

The deadweight loss is given by

$$\begin{aligned}
DWL(x_{t-1}) &= W_t^* - W_t \\
&= \int_0^{x_{t-1}^*+s_{t-1}} p^M(q)dq - \int_0^{x_{t-1}^*} p^S(q)dq + p_t^{LIV} s_{t-1} \\
&\quad - \int_0^{x_{t-1}+s_{t-1}} p^M(q)dq + \int_0^{x_{t-1}} p^S(q)dq - p_t^{LIV} s_{t-1} \\
&= \int_0^{s_{t-1}} p^M(q)dq + \int_{s_{t-1}}^{x_{t-1}^*+s_{t-1}} p^M(q)dq - \int_0^{x_{t-1}^*} p^S(q)dq \\
&\quad - \int_0^{s_{t-1}} p^M(q)dq - \int_{s_{t-1}}^{x_{t-1}+s_{t-1}} p^M(q)dq + \int_0^{x_{t-1}} p^S(q)dq
\end{aligned}$$

[5] Demand by consumers is given by the demand function: $c(p) = \frac{a_{Dt}}{b_D} - \frac{1}{b_D}p$. Demand by storers is given by the unknown, nonlinear storage function $s(p)$. Total demand by consumers and storers is given by $q = c(p) + s(p) = \frac{a_{Dt}}{b_D} - \frac{1}{b_D}p + s(p)$. The inverse of this function is the market demand function $p^M(q) = a_{Dt} - b_D q + f(q, a_{Dt})$ where the unkown, nonlinear, positive function $f(q, a_{Dt})$ denotes the inverse demand function of storers.

[6] Since the supply function is net of domestic demand, the producer surplus includes the surplus going to domestic producers, i.e., the efficiency effects on the US domestic industry are included in this analysis.

[7] I ignore transport cost for now to avoid cluttered notation, but will account for it in the empirical calculation.

Suppose without loss of generality that $x_{t-1} \leqslant x^*_{t-1}$:

$$DWL\left(x_{t-1}\right) = \int_{x_{t-1}+s_{t-1}}^{x^*_{t-1}+s_{t-1}} p^M(q)dq - \int_{x_{t-1}}^{x^*_{t-1}} p^S(q)dq$$

Substituting the limits of integration

$$\begin{aligned}
DWL\left(x_{t-1}\right) &= \int_0^{x^*_{t-1}-x_{t-1}} p^M(q+x_{t-1}+s_{t-1})dq - \int_0^{x^*_{t-1}-x_{t-1}} p^S(q+x_{t-1})dq \\
&= \int_0^{x^*_{t-1}-x_{t-1}} \left(p^M(q+x_{t-1}+s_{t-1}) - p^S(q+x_{t-1})\right) dq \\
&= \int_0^{x^*_{t-1}-x_{t-1}} \left(a_{Dt} - b_D\left(q+x_{t-1}+s_{t-1}\right) + f\left(q+x_{t-1}+s_{t-1}\right) - a_{St} - b_S(q+x_{t-1})\right) dq
\end{aligned}$$

Note that the value of the integrand equals the price difference $p_t^{LIV} - p_t^{NY}$ at the lower bound, and $p_t^{LIV}\left(x^*_{t-1}\right) - p_{t-1}^{NY}\left(x^*_{t-1}\right) = 0$ at the upper bound. The integrand is monotonically decreasing in between, and its slope is smaller than $b_D + b_S$ in absolute values, because $\frac{\partial f(q,a_{Dt})}{\partial q}$ is the inverse of the marginal propensity to store as a function of stock on hand, which is between 0 and 1 (see Williams and Wright 1991, p. 101):

$$\frac{\partial\left(p^M(q+s_{t-1}) - p^S\left(q\right)\right)}{\partial q} = -b_D + f'\left(q+x_{t-1}+s_{t-1}\right) - b_S > -\left(b_S+b_D\right)$$

Since the demand for storage is an increasing function of stock, $f\left(q+x_{t-1}+s_{t-1}, a_{Dt}\right) \geqslant f\left(x_{t-1}+s_{t-1}, a_{Dt}\right)$

$$\begin{aligned}
DWL\left(x_{t-1}\right) &\geqslant \int_0^{\tilde{q}} \left(a_{Dt} - b_D\left(q+x_{t-1}+s_{t-1}\right) + f\left(x_{t-1}+s_{t-1}, a_{Dt}\right) - a_{St} - b_S(q+x_{t-1})\right) dq \\
&= \int_0^{\tilde{q}} \left(p_t^{LIV} - p_t^{NY} - \left(b_D+b_S\right)q\right) dq =: \underline{DWL}
\end{aligned}$$

with $\tilde{q}$ such that $p_t^{LIV} - p_t^{NY} - \left(b_D+b_S\right)\tilde{q} = 0$, i.e. $\tilde{q} = \frac{p_t^{LIV}-p_t^{NY}}{b_D+b_S}$.
Integration yields

$$\begin{aligned}
\underline{DWL} &= \left(\left(p_t^{LIV} - p_t^{NY}\right)q - \frac{b_D+b_S}{2}q^2\right)\Big|_0^{\tilde{q}} \\
&= \left(p_t^{LIV} - p_t^{NY}\right)\tilde{q} - \frac{b_D+b_S}{2}\tilde{q}^2 \\
&= \left(p_t^{LIV} - p_t^{NY} - \frac{b_D+b_S}{2}\tilde{q}\right)\tilde{q} \\
&= \left(p_t^{LIV} - p_t^{NY} - \left(b_D+b_S\right)\tilde{q} + \frac{b_D+b_S}{2}\tilde{q}\right)\tilde{q}
\end{aligned}$$

From the definition of $\tilde{q}$:

$$
\begin{aligned}
\underline{DWL} &= \frac{b_D + b_S}{2} \tilde{q}^2 \\
&= \frac{b_D + b_S}{2} \left(\frac{p_t^{LIV} - p_t^{NY}}{b_D + b_S} \right)^2 \\
&= \frac{\left(p_t^{LIV} - p_t^{NY}\right)^2}{2\left(b_D + b_S\right)}
\end{aligned}
$$

□

Note that the benchmark case considers deviations from efficient exports (i.e., exports if merchants can foresee future market conditions), but it holds fixed the storage function (but not stock at the end of the period) as well as stock at the beginning of the period. Another benchmark for measuring deadweight loss could be the case in which the storage *function* also adjusts to perfect foresight. This measure of deadweight loss cannot be estimated empirically, as it depends on unobserved, efficient stock. However, below I consider changes in the deadweight loss compared to the benchmark before and after the telegraph, i.e., a differences-in-differences setting. In this case the benchmark welfare cancels out, as it is a common reference point, and I obtain the change in welfare before versus after the telegraph.

6.3 Alternative approach to efficiency estimation

The approach used in the paper uses the expected surplus from storage in the welfare of the period of the export transaction to account for future surpluses generated by stock at the end of the period. Alternatively, because there are no income effects and demand is intertemporally separable, I can aggregate static surpluses over a long time period, by the end of which these future surpluses are realized. In order to do this I need data on storage, which are available only weekly, so the welfare estimate will be cruder. Also, I need to take a stance on how to aggregate per-period welfare over time. On the other hand, I will not be forced to focus on a lower bound of the deadweight loss, and I will be able to see which agents benefit from the telegraph most.

As an alternative approach to efficiency estimation, I consider now only immediate, per-period welfare (i.e., expected future surplus from stock at the end of the period is left out):

$$
W_t = CS_t + SS_t + MS_t + PS_t
$$

Immediate consumer surplus is given by the area underneath the consumer demand function minus price paid:

$$
CS_t = \int_0^{c_t} p^D(q)\, dq - p_t^{LIV} c_t
$$

Substitute in the expression for prices in Liverpool, $p_t^{LIV} = a_{Dt} - b_D c_t$:

$$CS_t = \frac{b_D}{2}c_t^2$$

Similar for the producer surplus, using $p^{NY}_{t-1} = a_{S,t-1} + b_S x_{t-1}$:

$$PS_t = \frac{b_S}{2}x_{t-1}^2$$

The remaining surpluses remain as defined above, resulting in an expression for per-period welfare, which is

$$W_t = \frac{b_D}{2}c_t^2 + \left(p_t^{LIV} - p_{t-1}^{LIV}\right)s_{t-1} + \left(p_t^{LIV} - p_{t-1}^{NY}\right)x_{t-1} + \frac{b_S}{2}x_{t-1}^2$$

This alternative approach allows me to assess how this welfare gain is divided across the agents, see Table B.15.

References

Bank of England: 2016, 'Quarterly Bulletin 2016 Q2'.

Boyle, J. E.: 1934, *Cotton and the New Orleans Cotton Exchange. A Century of Commercial Evolution.* The Country Life Press.

Brown, J.: 1909, *A Hundred Years of Merchant Banking*. New York: Privately Printed.

Bruchey, S. W.: 1967, *Cotton and the Growth of the American Economy, 1790-1860; Sources and Readings.* New York, NY, USA: Harcourt, Brace & World.

Chapman, S.: 1984, *The Rise of Merchant Banking*, Economic history series. Taylor & Francis.

Chilosi, D. and G. Federico: 2015, 'Early globalizations: The integration of Asia in the world economy, 1800â1938'. *Explorations in Economic History* **57**, 1 – 18.

Clarke, A. C.: 1992, *How the World Was One: Towards the Tele-Family of Man*. New York, NY, USA: Bantam Books, Inc.

Deaton, A. and G. Laroque: 1996, 'Competitive Storage and Commodity Price Dynamics'. *Journal of Political Economy* **104**(5), 896–923.

Dumbell, S.: 1927, 'The Origin of Cotton Futures'. *Economic History Series (A Supplement to the Economic Journal)* **2**.

Ejrnæs, M. and K. G. Persson: 2010, 'The Gains from Improved Market Efficiency: Trade Before and After the Transatlantic Telegraph'. *European Review of Economic History* **14**(03), 361–381.

Ellison, T.: 1886, *The Cotton Trade of Great Britain*. Effingham Wilson.

Entz, J. F.: 1841, *Exchange and Cotton Trade between England and the United States*. New York: E. B. Clayton.

Farnie, D. A.: 1979, *The English cotton industry and the world market, 1815-1896*. Clarendon Press.

Farnie, D. A.: 2004, 'The Role of Merchants as Prime Movers in the Expansion of the Cotton Industry, 1760-1990'. In: D. A. Farnie and D. J. Jeremy (eds.): *The Fibre that Changed the World: The Cotton Industry in International Perspective, 1600-1990s*. Oxford University Press.

Farnie, D. A. and D. A. Gurr: 1998, 'Design and Construction of Mills'. Oldham Education and Leisure Services, pp. 15–24.

Gibbs, C. R. V.: 1957, *Passenger Liners of the Western Ocean: A Record of Atlantic Steam and Motor Passenger Vessels from 1838 to the Present Day*. Staples Press.

Greene, W. H.: 2003, *Econometric Analysis*. Upper Saddle River, NJ: Prentice Hall, 5th edition.

Hammond, M. B.: 1897, *The Cotton Industry: An Essay in American Economic History. Part 1, The Cotton Culture and the Cotton Trade*, Publications of the American economic association. American Economic Association.

Hanlon, W. W.: 2015, 'Necessity Is the Mother of Invention: Input Supplies and Directed Technical Change'. *Econometrica* **83**, 67–100.

Henderson, W. O.: 1969, *The Lancashire Cotton Famine 1861-65*. Manchester, UK: Manchester University Press.

Irwin, D. A.: 2003, 'The Optimal Tax on Antebellum US Cotton Exports'. *Journal of International Economics* **60**(2), 275–291.

Irwin, H. S.: 1954, *Evolution of futures trading*. Mimir Publishers.

Lew, B. and B. Cater: 2006, 'The Telegraph, Co-ordination of Tramp Shipping, and Growth in World Trade, 1870-1910'. *European Review of Economic History* **10**, 147–173.

Milne, G. J.: 2000, *Trade and Traders in Mid-Victorian Liverpool. Mercantile Business and the Making of a World Port*. Liverpool University Press.

Pippenger, J. and L. Phillips: 2008, 'Some Pitfalls in Testing the Law of One Price in Commodity Markets'. *Journal of International Money and Finance* **27**(6), 915–925.

Shaw, A. D.: 1882, *Extracts from a Special Report on the Cotton Goods Trade of Lancashire*. Alexander Ireland and Co.

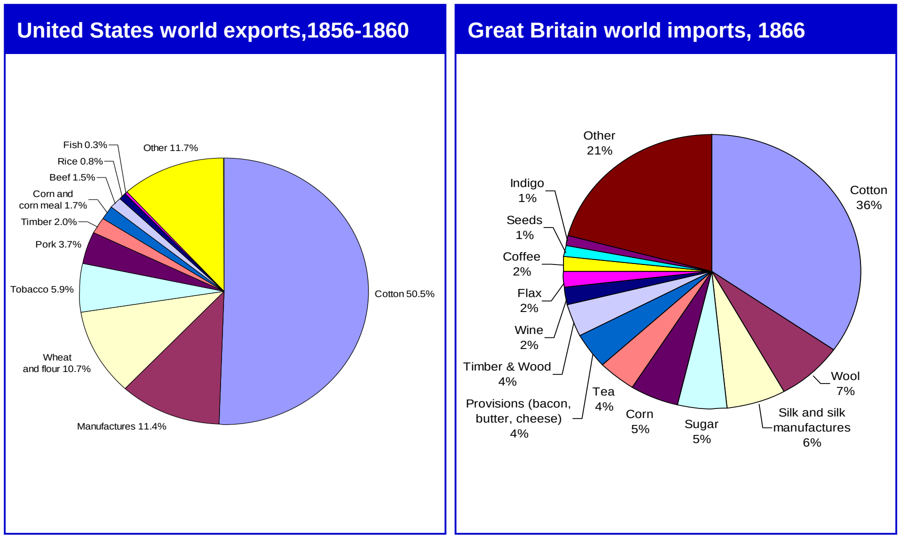
Surdam, D. G.: 1998, 'King Cotton: Monarch or Pretender? The State of the Market for Raw Cotton on the Eve of the American Civil War'. *The Economic History Review* **51**(1), 113–132.

The Economist: 1866, 'Accounts Relating to Trade And Navigation in the Eleven Months Ended November 30, 1866'.

Williams, J. C. and B. D. Wright: 1991, *Storage and Commodity Markets*. Cambridge University Press.

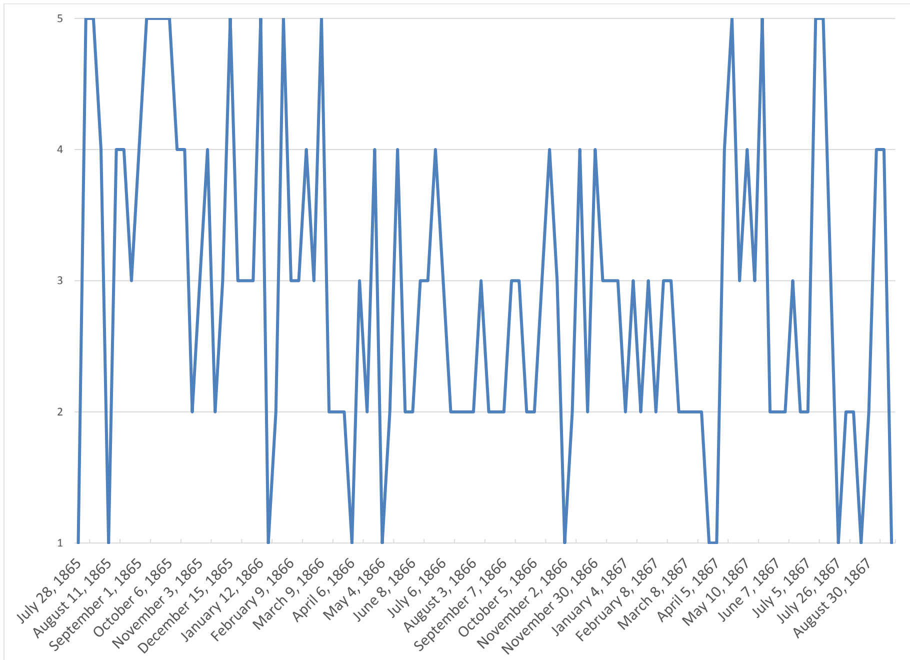
Woodman, H. D.: 1968, *King Cotton and His Retainers. Financing and Marketing the Cotton Crop of the South, 1800-1925*. Lexington.

A Figures



Sources: Bruchey 1967 (United States), The Economist 1866 (Great Britain).

Figure A.1: Importance of cotton in transatlantic trade



1: depressed/low demand/limited demand, 2: dull/languid/flat/inanimate,
3: Steady/no activity in demand/firm/quiet, 4: moderate/fair, 5: animated

Figure A.2: Demand conditions in the Manchester yarn market

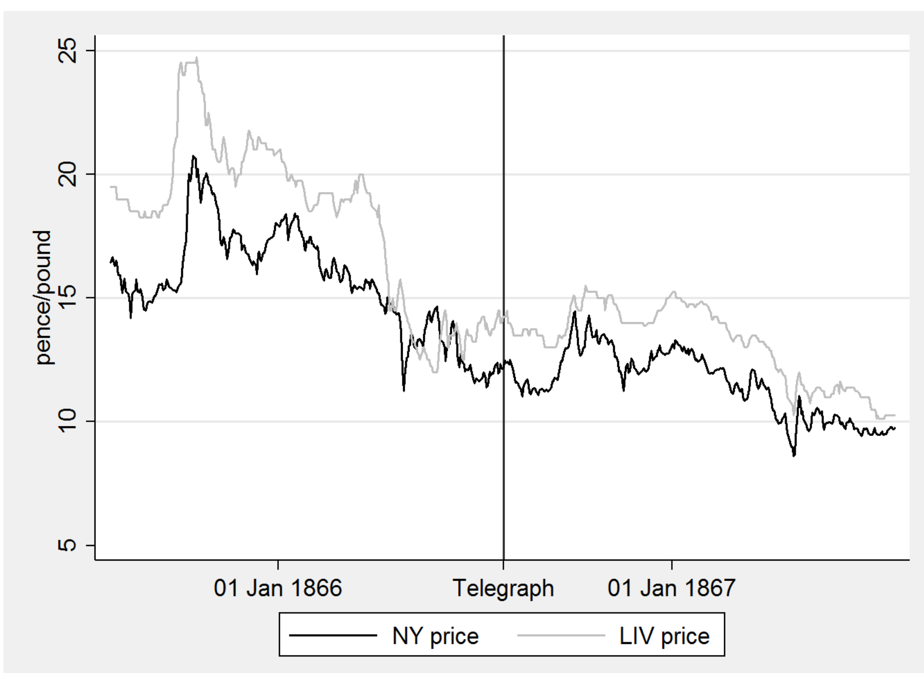


Figure A.3: Price series

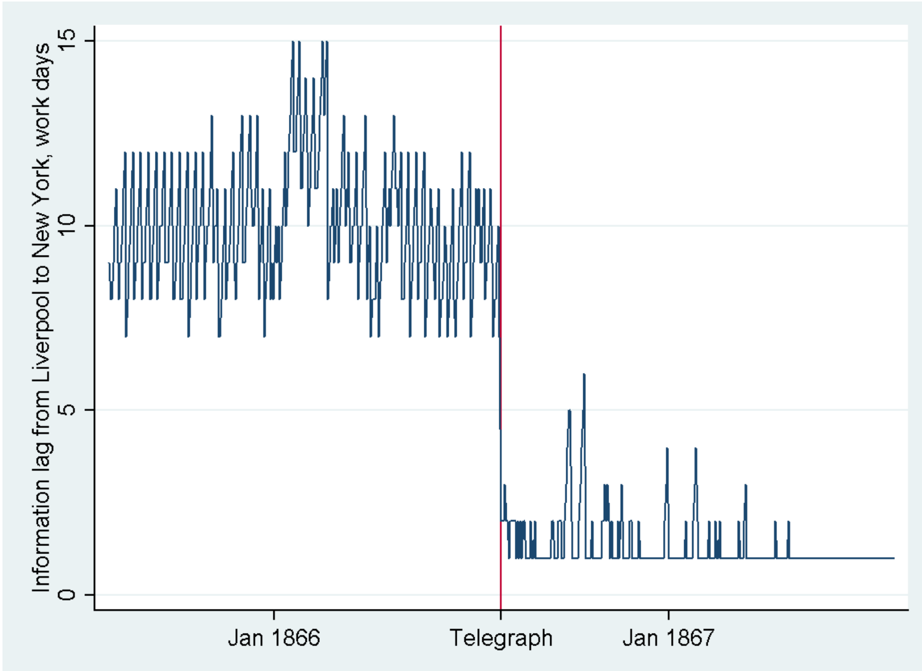


Figure A.4: Information delay between New York and Liverpool over time

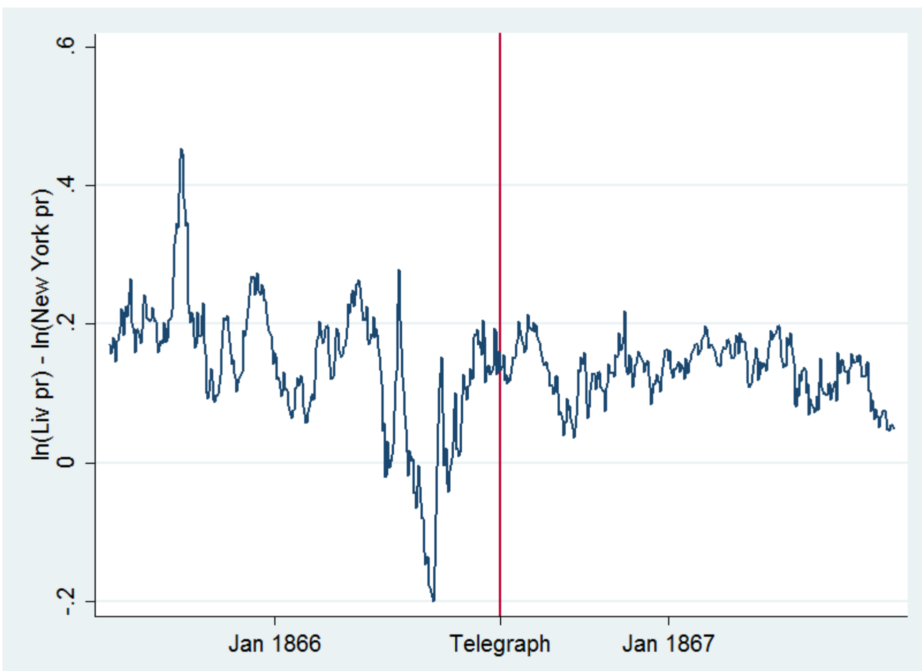


Figure A.5: Difference in log prices

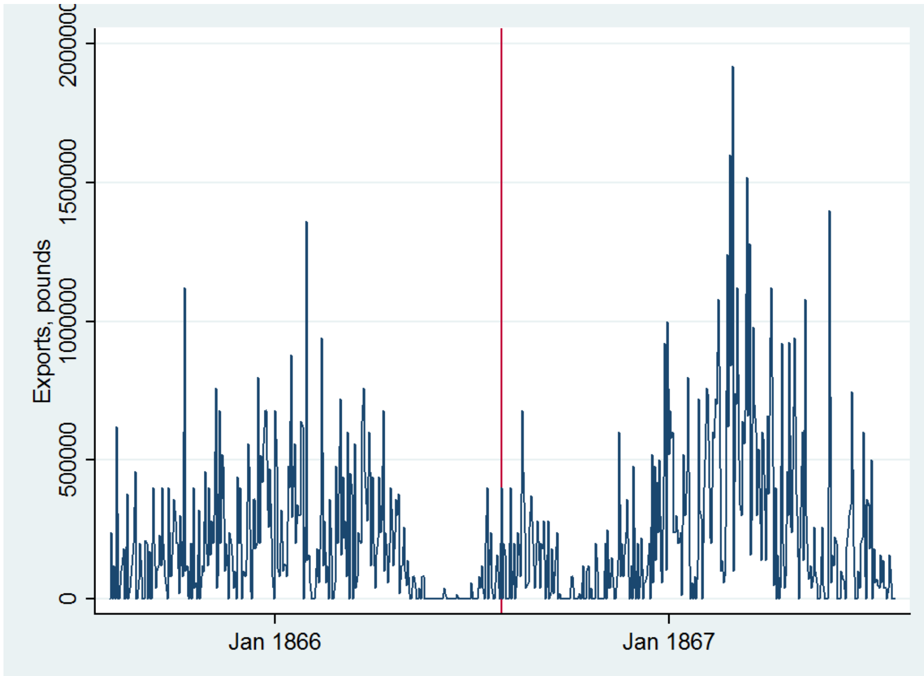
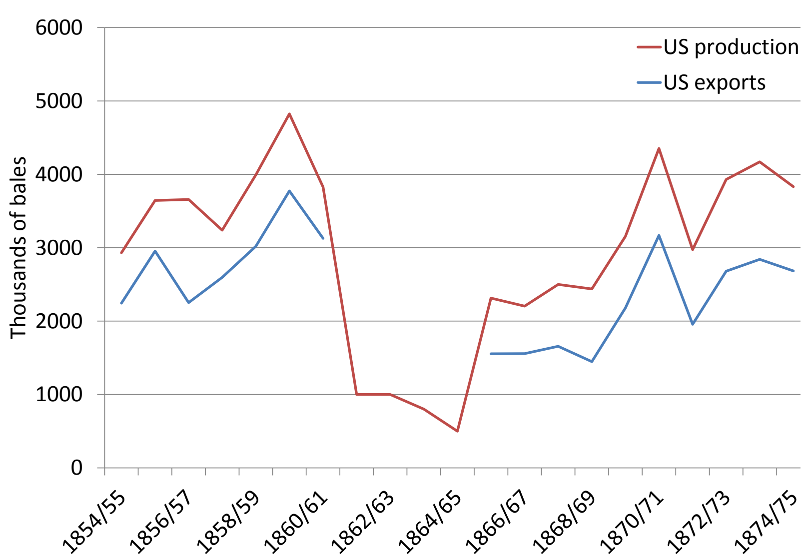


Figure A.6: Daily exports from New York to Liverpool



Source: Ellison (1886), except for production numbers during the Civil War (cotton year 1861/62 to 1864/65) which are estimates from New York Shipping and Commercial List as reproduced in Hammond (1897). Note that the cotton year starts 1 September and ends 31 August.

Figure A.7: Cotton production of the United States

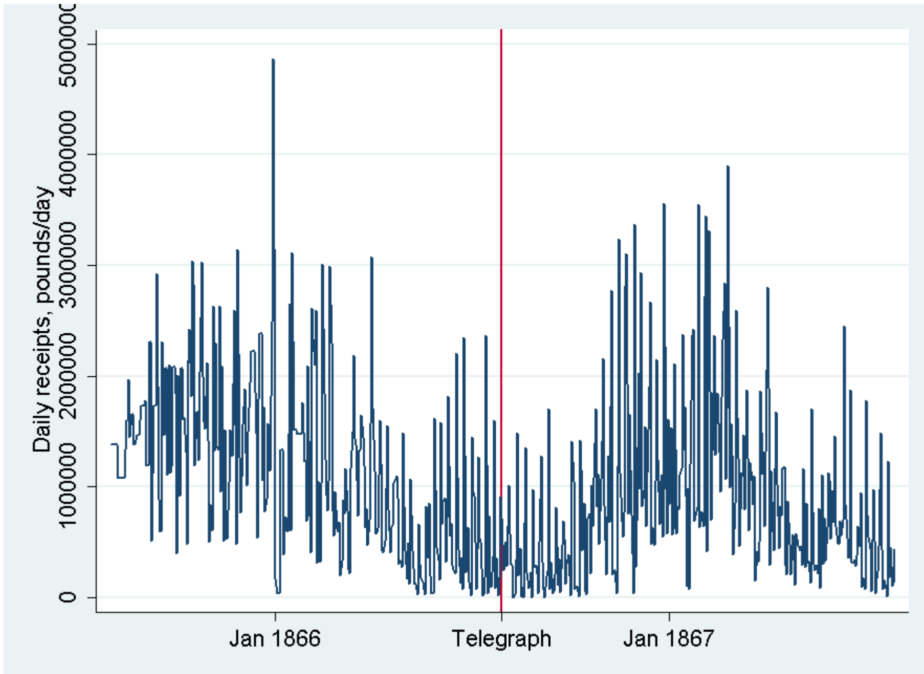


Figure A.8: Cotton receipts at the New York exchange

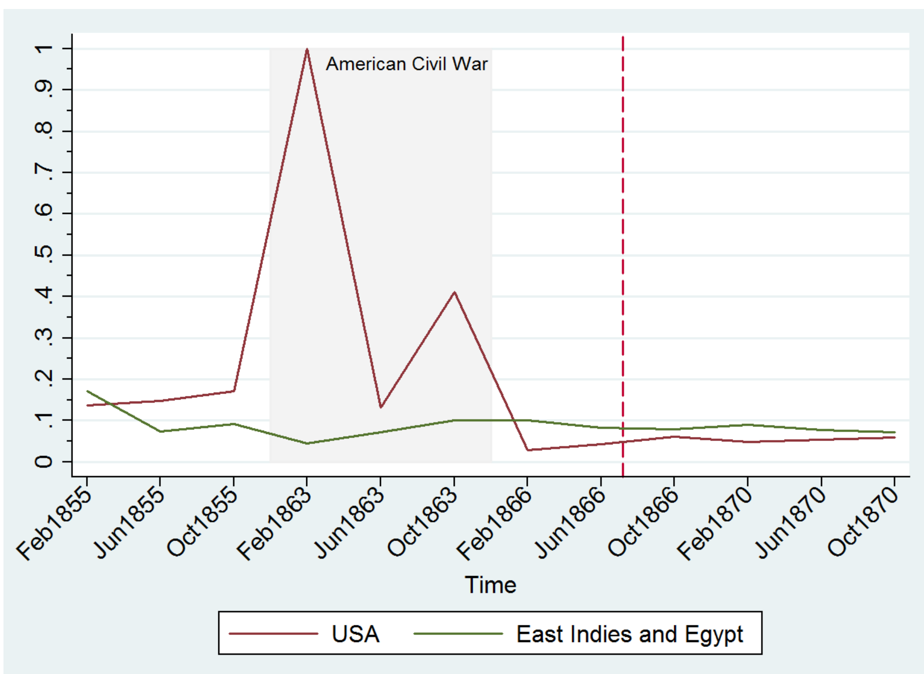
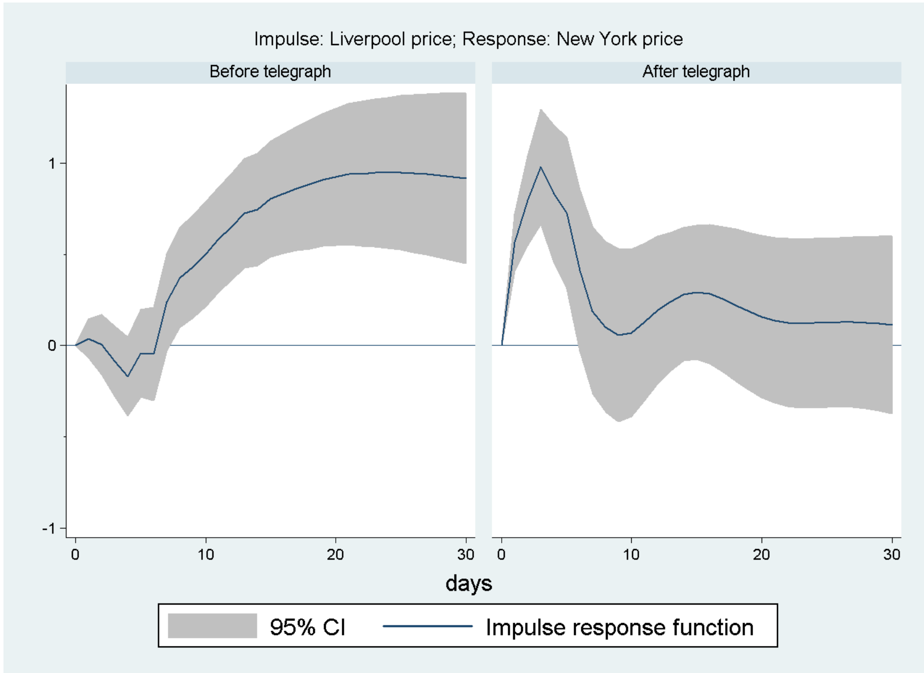
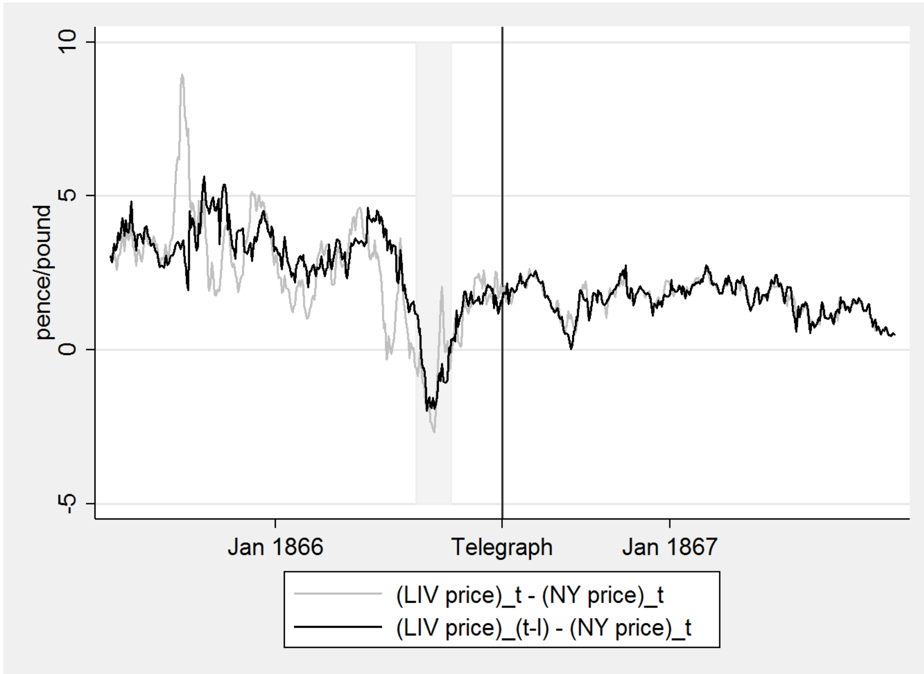


Figure A.9: Herfindahl index of market structure of cotton merchants



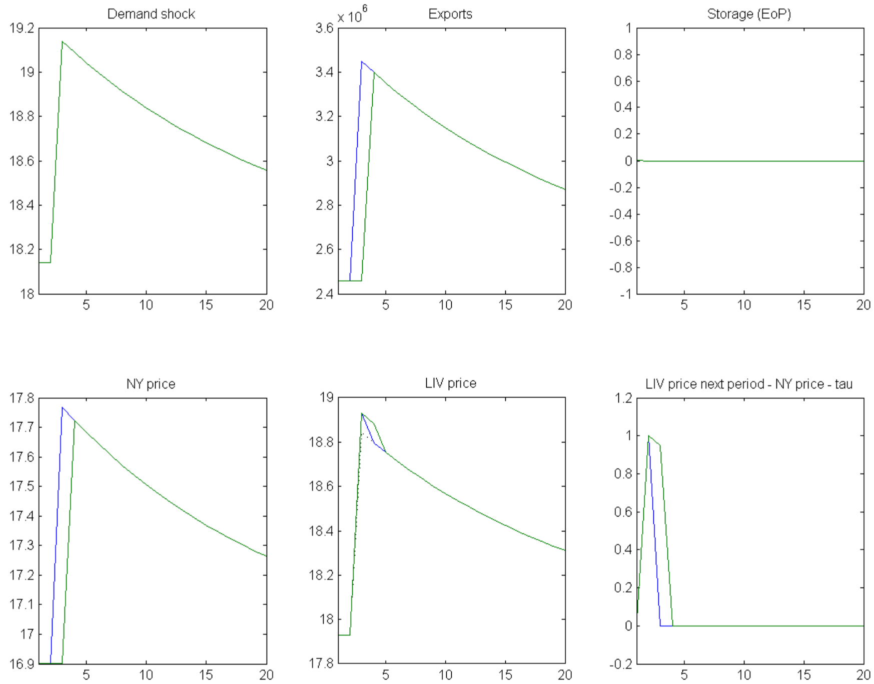
Note: Interestingly, the lags around 14 days are significant after the telegraph, because steam ships were used to ship longer market reports such as circulars.

Figure A.10: Impact of Liverpool price on New York price



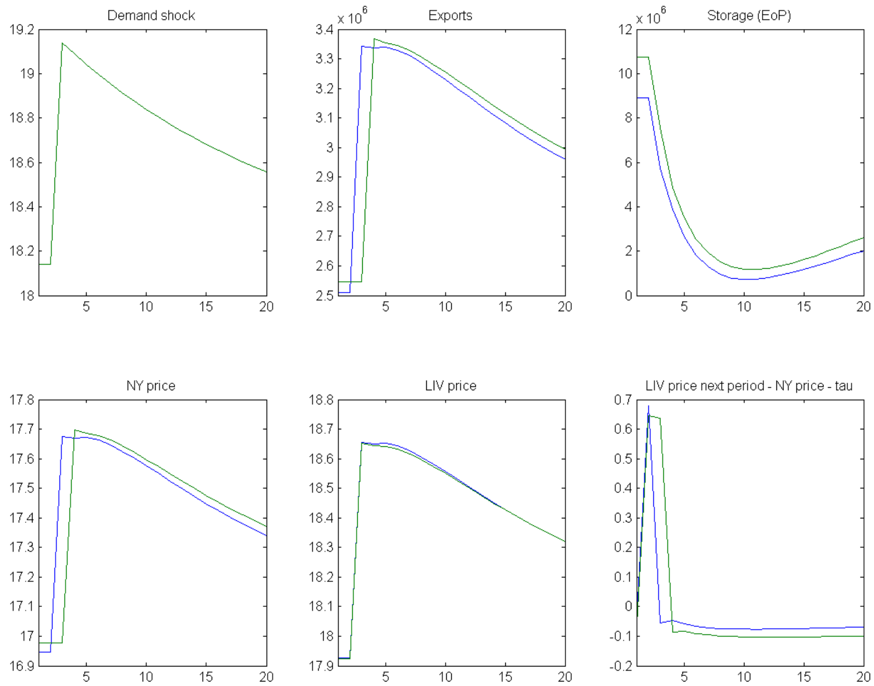
Note: The shaded area denotes the no-trade period, in which there were no exports from New York to Liverpool. *(LIV price)_(t-l)* denotes the last Liverpool price that is known in New York at time *t*, i.e., the price in Liverpool lagged by the information lag *l*. The contemporaneous price difference is given by the difference between the Liverpool and the New York price on the same day. Most of the largest price deviations disappear when the lagged price difference is compared to the contemporaneous price difference, except for the period of no trade in May 1866, which is shaded in the figure.

Figure A.11: Contemporaneous price difference and price difference to the known, delayed Liverpool price



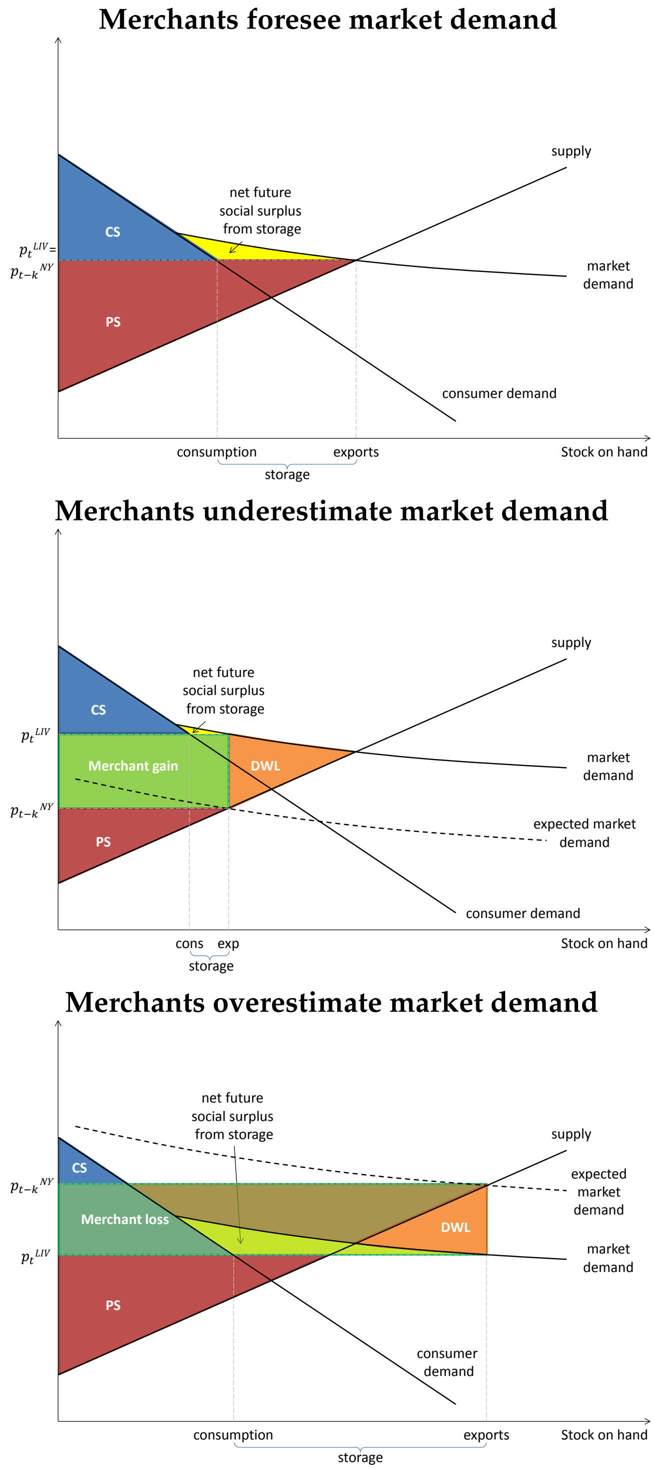
- delayed information (green line)
- instantaneous information (blue line)

Figure A.12: Impulse response function; no storage



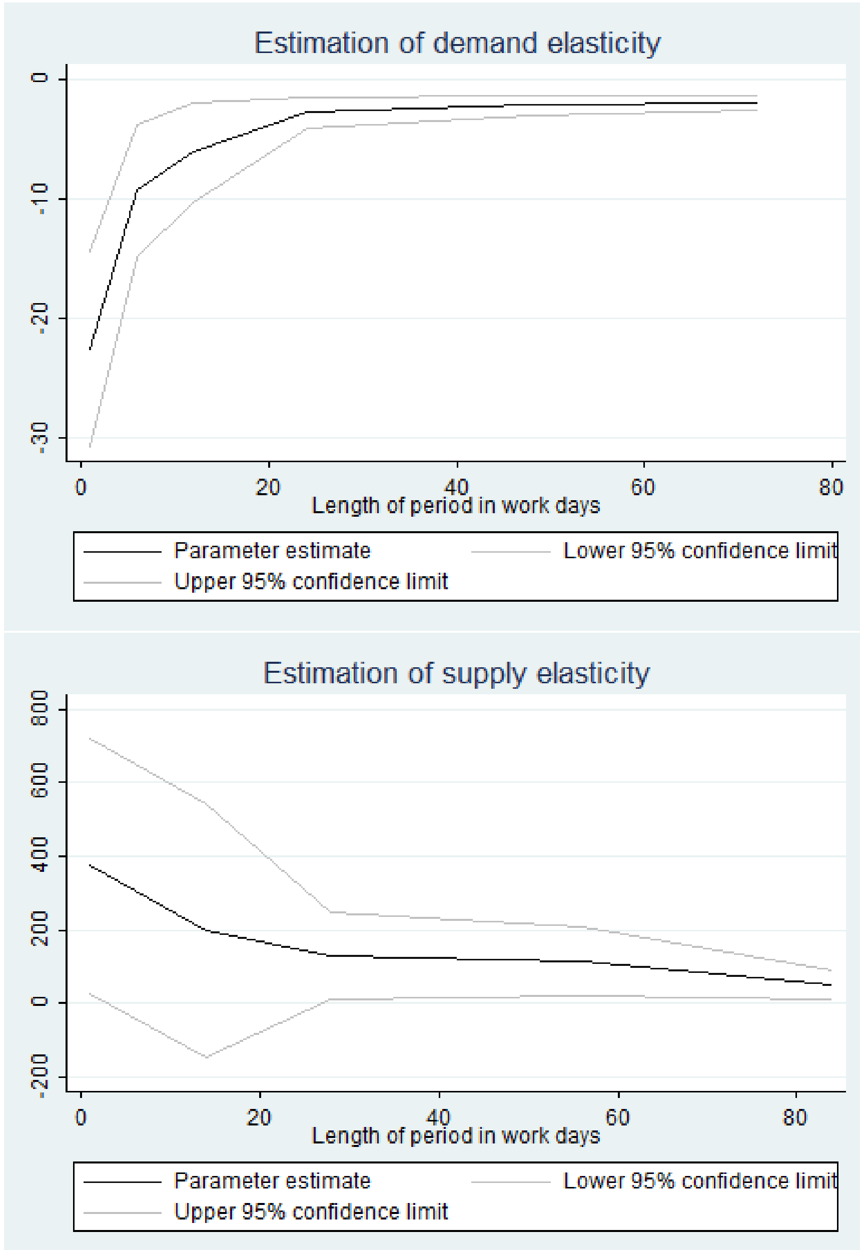
- delayed information (green line)
- instantaneous information (blue line)

Figure A.13: Impulse response function; storage



Notes: This figure illustrates how to think about a deadweight loss arising from information frictions. The top figure shows the efficient case, when merchants foresee market demand. Prices are equalized across markets, and welfare is maximized. The middle figure shows the case in which exports are smaller because market demand is underestimated. Consumer and producer surplus as well as the expected surplus from storage are smaller, while merchants make an unexpected profit. However, there is a deadweight loss compared to the case with efficient exports, illustrated by the orange area. The bottom figure shows the case in which merchants overestimate market demand. In this case, exports are larger than efficient exports. Merchants make a loss, and some of the inefficiently high export is stored for the future. However, optimal storage is not large enough to raise the Liverpool price to the level of the efficient price. The size of the deadweight loss is again given by the orange area. Note that figures are drawn for the case with no storage at the beginning of the period, but in the derivation of the theorem this is accounted for.

Figure A.14: Surplus from export transaction



Note: Elasticities are based on OLS estimations of demand and supply function on data aggregated by days as indicated by the x-axis. Confidence intervals are based on HAC robust standard errors.

Figure A.15: Demand and supply elasticities depending on length of period for estimation

B Tables

Table B.1: Composition of transport cost

	Share of total transport cost
Unit transport cost	**83.1**
Freight cost	65.2
Storage at port	4.9
Cartage, porterage, weighing	4.3
Bagging, twine, mending, marking	4.0
Dock dues	3.0
Postage and small charges	0.9
Wharfage	0.6
Insurance policy issuance fee	0.2
Ad valorem transport cost	**16.9**
Brokerage	10.2
Marine insurance	5.5
Town dues Liverpool	0.6
Fire insurance	0.6

Source: Boyle (1934) and own calculations

Table B.2: Effect of telegraph on average cotton price difference between Liverpool and New York

Dependent variable:	(1) $p_t^{LIV} - p_t^{NY}$	(2) $p_t^{LIV} - p_t^{NY} - \tau_t$	(3) $p_t^{LIV} - p_t^{NY} - \tau_t$	(4) $p_t^{LIV} - p_t^{NY} - \tau_t$	(5) $p_t^{LIV} - p_t^{NY} - \tau_t$	(6) $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$
Constant	2.56	2.17	1.52	1.84	1.45	1.34
	(0.18)	(0.17)	(0.17)	(0.15)	(0.16)	(0.21)
Telegraph dummy	-0.91	-0.83	-0.71	-1.03	-0.91	-0.87
	(0.19)	(0.18)	(0.18)	(0.16)	(0.15)	(0.21)
Cotton supply$_{t-1}$					0.13	0.10
					(0.03)	(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
Observations	604	604	604	575	575	575

Notes: As freight costs are not available for all the periods, they are interpolated when missing. The average freight cost is calculated as the average of sail and steam freight rate if both are available, or the freight rate that is available (assuming freight costs are not printed in newspapers if the freight type was not used). Total transport costs include the average freight cost, an additional 0.17 pence/pound unit freight cost, and 3.1% ad valorem transport costs (on the New York price). More details are provided in the text of the Online Appendix. Columns (4) 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. Columns (5) and (6) use the one-day lagged cotton supply (receipts, in thousand bales) to control for potential disruptions in cotton production after the American Civil War and any other supply shocks or seasonal supply patterns. In (6) the price in Liverpool at the time of the arrival of the shipment is used to adjust for the transport time of shipment (k is equal to the steam-ship travel time, which was used to transport the samples of cotton bales that could be used for transactions on the exchange). Newey West standard errors in parentheses (lag=2).

Table B.3: Average difference in log prices

Dependent variable:	(1) $\ln\left(p_t^{LIV}\right)-\ln\left(p_t^{NY}\right)$	(2) $\ln\left(p_t^{LIV}-\tau_t\right)-\ln\left(p_t^{NY}\right)$	(3) $\ln\left(p_t^{LIV}-\tau_t\right)-\ln\left(p_t^{NY}\right)$	(4) $\ln\left(p_t^{LIV}-\tau_t\right)-\ln\left(p_t^{NY}\right)$	(5) $\ln\left(p_t^{LIV}-\tau_t\right)-\ln\left(p_t^{NY}\right)$	(6) $\ln\left(p_{t+k}^{LIV}-\tau_t\right)-\ln\left(p_t^{NY}\right)$
Constant	0.144	0.123	0.085	0.106	-0.022	0.020
	(0.007)	(0.007)	(0.008)	(0.006)	(0.039)	(0.055)
Telegraph dummy	-0.011	-0.013	-0.017	-0.039	-0.033	-0.034
	(0.011)	(0.010)	(0.011)	(0.009)	(0.009)	(0.012)
ln(cotton supply)$_{t-1}$					0.009	0.005
					(0.003)	(0.004)
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
Observations	604	604	604	575	574	574

Notes: As freight costs are not available for all the periods, they are interpolated when missing. The average freight cost is calculated as the average of sail and steam freight rate if both are available, or the freight rate that is available (assuming freight costs are not printed in newspapers if the freight type was not used). Total transport costs include the average freight cost, an additional 0.17 pence/pound unit freight cost, and 3.1% ad valorem transport costs (on the New York price). In (4) 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. In (5) 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. In (6) the price in Liverpool at the arrival of the shipment (around 10 days in the future) is used to control for transport time of shipment. Newey West standard errors (lag=2) in parentheses.

Table B.4: Effect of telegraph on the variance in price difference of cotton between Liverpool and New York

Dependent variable: $\widehat{Var}$ of ...	(1) $p_t^{LIV}-p_t^{NY}$	(2) $p_t^{LIV}-p_t^{NY}-\tau_t$	(3) $p_t^{LIV}-p_t^{NY}-\tau_t$	(4) $p_t^{LIV}-p_t^{NY}-\tau_t$	(5) $p_t^{LIV}-p_t^{NY}-\tau_t$	(6) $p_{t+k}^{LIV}-p_t^{NY}-\tau_t$
Constant	3.36	3.17	3.09	2.19	2.15	3.88
	(0.59)	(0.56)	(0.56)	(0.46)	(0.40)	(0.77)
Telegraph dummy	-3.11	-2.96	-2.89	-1.99	-1.97	-3.80
	(0.59)	(0.56)	(0.56)	(0.46)	(0.43)	(0.86)
Cotton supply$_{t-1}$					0.01	0.12
					(0.08)	(0.13)
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
Observations	604	604	604	575	575	575

Notes: $\widehat{Var}\left(x_t\right) := \frac{N_{before}}{N_{before}-1}\left(x_t-\bar{x}_{before}\right)^2$ if the observation is before the telegraph, and $\widehat{Var}\left(x_t\right) := \frac{N_{after}}{N_{after}-1}\left(x_t-\bar{x}_{after}\right)^2$ 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. The columns repeat the specifications from Table B.2. Newey West standard errors in parentheses (lag=2).

Table B.5: Normalized variance of price difference

Dependent variable: $\widehat{Var}\left(pdiff_t\right)/\overline{pdiff}$ with $pdiff_t =$...	(1) $p_t^{LIV} - p_t^{NY}$	(2) $p_t^{LIV} - p_t^{NY} - \tau_t$	(3) $p_t^{LIV} - p_t^{NY} - \tau_t$	(4) $p_t^{LIV} - p_t^{NY} - \tau_t$	(5) $p_t^{LIV} - p_t^{NY} - \tau_t$	(6) $p_{t+k}^{LIV} - p_t^{NY} - \tau_t$
Constant	1.32	1.46	2.03	1.19	1.19	2.37
	(0.23)	(0.26)	(0.37)	(0.25)	(0.22)	(0.47)
Telegraph dummy	-1.16	-1.30	-1.78	-0.94	-0.94	-2.01
	(0.23)	(0.26)	(0.37)	(0.25)	(0.23)	(0.52)
Cotton supply$_{t-1}$					-0.00	0.06
					(0.04)	(0.08)
Transport costs τ_t include:						
Freight cost		yes	yes	yes	yes	yes
Other transport cost			yes	yes	yes	yes
Exclude no-trade periods				yes	yes	yes
Observations	604	604	604	575	575	575

Note: $\widehat{Var}\left(pdiff_t\right)/\overline{pdiff}$ is given by $\frac{N_{before}}{N_{before}-1}\frac{\left(pdiff_t-\overline{pdiff}_{before}\right)^2}{\overline{pdiff}_{before}}$ and $\frac{N_{after}}{N_{after}-1}\frac{\left(pdiff_t-\overline{pdiff}_{after}\right)^2}{\overline{pdiff}_{after}}$. The columns repeat the different specifications as in the tables for the variance of the price difference. Newey West standard errors (lag=2) in parentheses.

Table B.6: Vector autoregressions before and after the telegraph

	(1)	(2)	(3)	(4)
	Before telegraph		After telegraph	
	p_t^{LIV}	p_t^{NY}	p_t^{LIV}	p_t^{NY}
***LIV* price:**				
p_{t-1}^{LIV}	1.242	0.044	1.100	0.567
	(0.057)	(0.054)	(0.062)	(0.079)
p_{t-2}^{LIV}	-0.233	-0.098	-0.104	-0.377
	(0.091)	(0.085)	(0.088)	(0.112)
p_{t-3}^{LIV}	-0.081	-0.005	-0.055	0.033
	(0.092)	(0.086)	(0.088)	(0.112)
p_{t-4}^{LIV}	0.152	0.004	-0.046	-0.274
	(0.092)	(0.086)	(0.087)	(0.111)
p_{t-5}^{LIV}	0.023	0.191	-0.143	0.116
	(0.092)	(0.086)	(0.087)	(0.110)
p_{t-6}^{LIV}	-0.075	-0.206	0.150	-0.148
	(0.092)	(0.086)	(0.087)	(0.111)
p_{t-7}^{LIV}	-0.124	0.404	0.016	0.031
	(0.093)	(0.087)	(0.088)	(0.112)
p_{t-8}^{LIV}	0.237	-0.330	-0.037	0.067
	(0.096)	(0.090)	(0.088)	(0.111)
p_{t-9}^{LIV}	-0.243	0.066	0.053	-0.050
	(0.098)	(0.091)	(0.088)	(0.112)
p_{t-10}^{LIV}	0.087	-0.018	-0.024	0.043
	(0.063)	(0.059)	(0.063)	(0.080)
***NY* price:**				
p_{t-1}^{NY}	-0.039	1.177	0.063	0.968
	(0.062)	(0.058)	(0.049)	(0.063)
p_{t-2}^{NY}	0.116	-0.441	-0.013	-0.098
	(0.095)	(0.089)	(0.067)	(0.086)
p_{t-3}^{NY}	-0.067	0.358	-0.058	-0.018
	(0.097)	(0.091)	(0.067)	(0.085)
p_{t-4}^{NY}	0.065	-0.160	0.108	0.025
	(0.096)	(0.090)	(0.067)	(0.085)
p_{t-5}^{NY}	-0.026	-0.016	-0.021	0.023
	(0.095)	(0.089)	(0.066)	(0.084)
p_{t-6}^{NY}	-0.070	-0.012	0.000	0.014
	(0.094)	(0.087)	(0.065)	(0.083)
p_{t-7}^{NY}	0.059	0.042	-0.043	-0.002
	(0.093)	(0.087)	(0.065)	(0.082)
p_{t-8}^{NY}	-0.041	-0.036	0.094	0.092
	(0.092)	(0.086)	(0.065)	(0.082)
p_{t-9}^{NY}	-0.033	0.016	-0.077	-0.127
	(0.089)	(0.083)	(0.063)	(0.080)
p_{t-10}^{NY}	0.048	-0.012	0.057	0.102
	(0.057)	(0.053)	(0.044)	(0.056)
Observations	301	301	303	303

Notes: Columns (1) and (2) are the results from a vector autoregression of the *LIV* price and the *NY* price on the sample before the telegraph; columns (3) and (4) are the results from running the same vector autoregression on the sample after the telegraph. Standard errors in parentheses.

Table B.7: Effect of telegraph on exports from New Orleans, weekly data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	exp_t	exp_t	exp_t	exp_t	exp_t	exp_t	exp_t	$\ln(exp_t)$	$\ln(exp_t)$
Constant	7.76	-2.53	-10.67	7.48	-15.51	2.96	-15.49	-4.40	3.27
	(1.95)	(3.76)	(7.51)	(2.23)	(6.98)	(3.16)	(7.05)	(4.83)	(3.55)
Telegraph dummy	6.12	7.72	9.28	6.39	11.02	6.94	11.01	0.90	1.47
	(2.86)	(2.38)	(2.44)	(3.06)	(2.25)	(2.90)	(2.14)	(0.34)	(0.17)
Transport costs τ_t		30.21	19.16		23.04		22.98		3.30
		(12.39)	(8.80)		(8.48)		(9.46)		(0.82)
Cotton supply$_t$						0.00	0.00		
						(0.00)	(0.00)		
ln(cotton supply$_t$)								0.39	-0.32
								(0.31)	(0.24)
Transport costs τ_t include:									
Freight cost		avg	avg		avg		avg		avg
Other transport costs			yes		yes		yes		yes
Excluding no-trade periods				yes	yes	yes	yes	yes	yes
Observations	40	40	40	37	37	37	37	35	35

Notes: The dependent variable is weekly exports from New Orleans to the world (Source: *The Commercial & Financial Chronicle*). The sample includes only weeks in the year for which I have values for both the year before and the year after the telegraph (which occurs only in the months January to July, and not for all weeks in those months). Exports are in thousand bales. Transport cost and cotton supply data are the same as in the main tables in the paper, but aggregated to weeks. For more details on the data see section 4.4 in this Online Appendix. The sample in columns (8) and (9) drops because of observations with zero cotton supply. Newey West standard errors (lag=2) in parentheses.

Table B.8: Effect of telegraph on total US exports, weekly data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	exp_t	exp_t	exp_t	exp_t	exp_t	exp_t	exp_t	$\ln(exp_t)$	$\ln(exp_t)$
Constant	29.89	-6.39	-47.07	32.03	-49.83	10.06	-50.47	-9.81	2.05
	(6.83)	(6.65)	(12.40)	(7.82)	(13.69)	(11.15)	(12.16)	(4.54)	(4.36)
Telegraph dummy	8.80	12.20	20.31	6.66	21.29	8.34	21.47	0.52	1.17
	(9.26)	(5.31)	(5.43)	(10.01)	(5.88)	(8.27)	(5.31)	(0.38)	(0.29)
Transport costs τ_t		110.78	82.20		84.43		85.75		4.21
		(16.63)	(13.55)		(14.26)		(15.89)		(0.95)
Cotton supply$_t$						0.00	-0.00		
						(0.00)	(0.00)		
ln(cotton supply$_t$)								0.84	-0.20
								(0.28)	(0.32)
Transport costs τ_t include:									
Freight cost		avg	avg		avg		avg		avg
Other transport costs			yes		yes		yes		yes
Excluding no-trade periods				yes	yes	yes	yes	yes	yes
Observations	38	38	38	35	35	35	35	35	35

Notes: The dependent variable is weekly exports from all ports of the United States to the world (Source: *The Commercial & Financial Chronicle*). The sample includes only weeks in the year for which I have values for both the year before and the year after the telegraph (which occurs only in the months January to July, and not for all weeks in those months). Exports are in thousand bales. Transport cost and cotton supply data are the same as in the main tables in the paper, but aggregated to weeks. For more details on the data see section 4.4 in this Online Appendix. Newey West standard errors (lag=2) in parentheses.

Table B.9: Variance of exports from New York to Liverpool - added dummy for banking crisis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)$	$\widehat{Var}(exp)/\overline{exp}$	$\widehat{Var}(exp)/\overline{exp}$
Constant	0.34	-0.46	-1.06	0.34	-1.07	0.14	-1.08	0.34	-1.72
	(0.05)	(0.29)	(0.53)	(0.05)	(0.54)	(0.08)	(0.54)	(0.14)	(0.95)
Telegraph dummy	0.30	0.49	0.60	0.31	0.62	0.37	0.63	0.46	0.91
	(0.11)	(0.16)	(0.20)	(0.11)	(0.21)	(0.13)	(0.21)	(0.23)	(0.37)
Banking crisis dummy	-0.24	0.10	0.09	-0.25	0.04	-0.16	0.07	-0.27	0.12
(10 May 1866 to 30 Aug 1866)	(0.06)	(0.12)	(0.12)	(0.07)	(0.12)	(0.06)	(0.12)	(0.11)	(0.21)
Transport costs		1.91	1.29		1.29		1.17		1.99
		(0.71)	(0.49)		(0.50)		(0.49)		(0.87)
Cotton supply$_{t-1}$						0.06	0.04	0.09	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: $\widehat{Var}(x_t) := \frac{N_{before}}{N_{before}-1}\left(x_t - \bar{x}_{before}\right)^2$ if the observation is before the telegraph, and $\widehat{Var}(x_t) := \frac{N_{after}}{N_{after}-1}\left(x_t - \bar{x}_{after}\right)^2$ 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. Newey West standard errors (lag=2) in parentheses.

Table B.10: Average log exports from New York to Liverpool

Dependent variable:	(1) ln(exp)	(2) ln(exp)	(3) ln(exp)	(4) ln(exp)	(5) ln(exp)	(6) ln(exp)	(7) ln(exp)
Constant	12.09	10.92	9.68	12.13	9.85	9.54	8.38
	(0.07)	(0.20)	(0.40)	(0.07)	(0.41)	(0.69)	(0.67)
Telegraph dummy	0.14	0.41	0.67	0.10	0.62	0.20	0.63
	(0.12)	(0.11)	(0.13)	(0.12)	(0.14)	(0.12)	(0.14)
Transport costs τ_t		2.78	2.22		2.09		1.85
		(0.47)	(0.37)		(0.38)		(0.38)
ln(Cotton supply$_{t-1}$)						0.19	0.13
						(0.05)	(0.04)
Transport costs τ_t include:							
Freight cost		yes	yes		yes		yes
Other transport costs			yes		yes		yes
Excluding no-trade periods				yes	yes	yes	yes
Observations	451	451	451	444	444	443	443

Notes: Exports are in thousand bales. The sample drops as log exports are taken and some instances with 0 exports are dropped. Newey West standard errors (lag=4) in parentheses.

Table B.11: Normalized variance of exports from New York to Liverpool

Dependent variable: $\widehat{Var}\left(exp\right)/\overline{exp}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.63	-0.53	-1.54	0.59	-1.65	0.26	-1.59
	(0.09)	(0.39)	(0.71)	(0.08)	(0.83)	(0.13)	(0.74)
Telegraph dummy	0.35	0.58	0.77	0.39	0.87	0.49	0.88
	(0.21)	(0.26)	(0.31)	(0.21)	(0.35)	(0.21)	(0.31)
Transport cost τ_t		3.05	2.10		2.11		1.89
		(1.04)	(0.70)		(0.79)		(0.71)
Cotton supply$_{t-1}$						0.11	0.06
						(0.03)	(0.03)
Transport costs τ_t include:							
Freight cost		yes	yes		yes		yes
Other transport cost			yes		yes		yes
Exclude no-trade periods				yes	yes	yes	yes
Observations	604	604	604	575	575	575	575

Note: The dependent variable is given by $\frac{N_{before}}{N_{before}-1}\frac{\left(exp_t-\overline{exp}_{before}\right)^2}{\overline{exp}_{before}}$ and $\frac{N_{after}}{N_{after}-1}\frac{\left(exp_t-\overline{exp}_{after}\right)^2}{\overline{exp}_{after}}$, so that the coefficient on the constant yields the sample variance/mean on the period before the telegraph, and the coefficient on the telegraph dummy yields the change in the sample variance/mean before versus after the telegraph. Exports are in thousand bales. Newey West standard errors (lag=4) in parentheses.

Table B.12: Prices of different cotton qualities

Variety of cotton (quality type; ordered from highest to lowest)	**Price in % of middling price**
Middling fair	113.5%
Good Middling	108.1%
Strict Middling	104.1%
Middling	*100.0%*
Low Middling	95.9%
Good Ordinary	86.5%
Ordinary	81.1%

Source: Circular of Mr. Wm. P. Wright, printed in *The New York Times* of September 26, 1866.

Table B.13: Liverpool stock of American cotton (per December 31 of each year) in percent of annual imports of American cotton

Year	**Stock in % of imports**
1855	14.6
1856	10.1
1857	13.7
1858	14.4
1859	14.7
1860	15.3
1865	31.2
1866	14.4
1867	8.5
1868	6.5
1869	7.4
1870	6.6

Source: Ellison (1886, Table 1). Civil War years excluded, as they were highly irregular. Note that these data refer to calendar years, whereas my data covers a year before and after the introduction of the telegraph in July 1866.

Table B.14: Parameters for calibration

Parameter	Value	Method
Demand side (Liverpool):		
b_D	-0.032	Instrumental variables estimation using data aggregated over 10-day periods
$\bar{a}_D$	18.32	Fitting AR(1) process on residual from demand curve estimation
ρ_D	0.86	Fitting AR(1) process on residual from demand curve estimation
$SD(a_{Dt})$	3.07	Fitting AR(1) process on residual from demand curve estimation
Supply side (New York):		
b_S	0.185	Instrumental variables estimation using data aggregated over 10-day periods
$\bar{a}_S$	15.03	Fitting AR(1) process on residual from supply curve estimation
ρ_S	0.48	Fitting AR(1) process on residual from supply curve estimation (only used in extension of model)
$SD(a_{St})$	2.30	Fitting AR(1) process on residual from supply curve estimation (only used in extension of model)
Other parameters:		
Transport cost τ	1.03	Total transport cost as estimated in empirical section
Storage cost θ	0.0229	From Boyle (1934) and Entz (1841), including storage rate, interest rate on capital, and waste

Table B.15: Welfare estimation based on current surpluses only

Share of total surplus change	**Storage in *LIV***	**Storage in *LIV* and *NY***
Consumer	18.3%	4.8%
Producer	74.8%	37.5%
Merchant	3.6%	0.9%
Storers in *LIV*	3.3%	0.9%
Storers in *NY*		55.9%

Notes: Allowing for storage in New York affects the calculation of the surplus of producers, as some stock may have been produced in the past. Calculation based on data aggregated over 10-day periods.