Industry Connections and the Geographic Location of Economic Activity*

W. Walker Hanlon

UCLA Department of Economics

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Abstract

This paper provides causal evidence that inter-industry connections can influence the geographic location of economic activity. To do so, it takes advantage of a large, exogenous, temporary, and industry-specific shock to the 19th century British economy. The shock was caused by the U.S. Civil War, which sharply reduced raw cotton supplies to Britain's important cotton textile industry, causing a four-year recession in the industry. The impact of the shock on towns in Lancashire County, the center of Britain's cotton textile industry, is compared to towns in neighboring Yorkshire County, where wool textiles dominated. The results suggest that this trade shock reduced relateive employment growth in industries that were more related to the cotton textile industry, in towns that were more severely impacted by the shock. The impact persists for over two decades after the end of the U.S. Civil War, suggesting that temporary shocks, acting through inter-industry connections, can have long-term impacts on the distribution of industrial activity across locations.

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1 Introduction

Marshall (1890) suggested that firms in different industries may benefit from locating near to one another, through localized inter-industry spillovers. He identified three channels through which these benefits could flow: input-output linkages, labor market pooling, and technology spillovers. Since then, inter-industry spillovers have been incorporated into theories of industrial linkages and development (Hirschman (1958), Ciccone (2008)), industrial clusters (Porter (1990)), the benefits of urban economies (Jacobs (1969)), the benefits of trade and FDI (Young (1991), Rodriguez-Clare (1996)), and the geography of economic activity (Krugman & Venables (1995)). Policy makers, too, have been influenced by these ideas. The existence of inter-industry spillovers is one of the prime motivations for local industrial policies, such as the tax incentives offered to firms by U.S. municipalities, or the widespread use of special industrial zones in developing countries. The cost of these policies can run into the hundreds of millions of dollars for single U.S. municipalities.[1]

Despite this interest, and widespread application, empirical evidence on the role of inter-industry connections in influencing the geographic location of economic activity is sparse. This is due largely to the difficulty of measuring the patterns of connections between industries, though these measures are improving.[2] In an important recent study, Greenstone *et al.* (2010) show evidence of localized productivity spillovers between plants that share similar labor or technology pools.[3] In a similar vein, Javorcik (2004) finds evidence of spillovers from FDI firms to upstream suppliers.[4] More related to the current study is Ellison *et al.* (2010), which uses measures of input-output connections, labor force similarity, and technological spillovers, to provide evidence that the underlying pattern of connections between industries is reflected in the geographic location of industries. While these are important contributions, they do

[1] See Greenstone & Moretti (2004).

[2] There are a number of early studies which looked for the impact of inter-industry connections without accounting for the patterns that these connections take. Important contributions include Glaeser *et al.* (1992), Kim (1995), Henderson (1997), and Henderson (2003). There is also a much larger literature considering the role of spillovers within industries.

[3] Another interesting contribution is Bloom *et al.* (2007).

[4] Similar evidence is also provided by Kugler (2006), Poole (forthcoming), and Balsvik (Forthcoming).

not address one of the most relevant questions for policy: can *temporary changes* in the local availability of inter-industry spillovers, such as those created by economic shocks or policy interventions, have long-term impacts on the geographic location of economic activity?

This study takes the next step, by utilizing a large temporary external shock that altered the spillovers available to certain industries in certain locations, in order to provide causal evidence that changes in the availability of inter-industry spillovers can influence the long-run distribution of economic activity. The shock was caused by the U.S. Civil War and impacted the British economy in the 1860s. During the 19th century, cotton textile production was the largest British manufacturing industry, and cotton textiles were Britain's largest export. This industry relied entirely on imports of raw cotton, a vital input. Prior to the onset of the U.S. Civil War in 1861, the majority of raw cotton (77% in 1860) came from the Southern U.S., but the war, and the corresponding Union blockade of Southern ports, sharply reduced raw cotton supplies. The result was a four-year depression in the industry, lasting from roughly 1861-1865. My focus is on how this affected the location of those industries *related to* (sharing spillovers with) the cotton textile industry.

This event has several features that are particularly helpful in identifying the effects of interest. First, the shock was large, exogenous, and had only a temporary impact on cotton textile industry output. While the cotton shortage reduced production by about half during the shock period, the cotton textile industry rebounded quickly, attaining its original growth path by roughly 1866-67, only a year or two after the end of the war. Second, the direct effects of the shock were largely *industry-specific*. British import and export data suggest that, once textiles are removed, the shock had no major effect on other British manufacturing sectors (excluding arms). Thus, changes observed in those industries related to cotton textiles can be attributed to the shock, transmitted through inter-industry connections. Third, despite the large magnitude of the negative effects of the cotton shortage, there was virtually no government intervention. This was largely due to the very strong free-market ideology that was dominant in Britain at the time, particularly in the northern industrial districts that were hardest hit by the recession.

A final important feature is that while some locations were severely impacted, other economically similar locations were left nearly untouched. This study compares outcomes in towns from two industrial counties in the north of England, Lancashire and Yorkshire. Lancashire was the heart of Britain's cotton textile industry at the time. Yorkshire, lying just to the east, was similar to Lancashire in many ways. The key difference between these two counties was that while towns in Yorkshire also had large textile industries, Yorkshire producers focused primarily on wool-based textiles (woolens & worsted) rather than cotton. Thus, while towns in Lancashire were severely affected by the cotton shortage, towns in Yorkshire were generally not negatively impacted. Comparing industry growth rates from towns in these two counties thus allows me to identify the impact of the shock while controlling for time-varying industry-level factors.

The basic hypothesis that I test is that the shock negatively affected employment and employment growth in industries more closely related to the cotton textile industry, in locations more severely impacted by the shock, by reducing the spillover benefits available to these industries. Importantly, I focus on longer-term impacts, those occurring in the years and decades after the Civil War had ended and the cotton textile industry had rebounded. There are several channels through which a temporary loss of inter-industry connections can generate persistent impacts of this kind. In the presence of localized economies of scale at the industry level, such as those generated by learning-by-doing spillovers between related firms, a temporary shock to industry size in some locations can have a long-term impact on the relative size of the industry in those locations. Similar results could be generated or magnified by inter-industry spillovers; if industries i and j benefit from mutual inter-industry connections, and are also related to the cotton textile industry, then a shock to the cotton textile industry that affects these industries in one period will also reduce the mutual benefits they generate, with a persistent and mutually reinforcing result. This study allows us to observe whether inter-industry connections can generate long-term impacts through channels such as these, though it will not be possible to observe which particular channel is driving the observed effects.

The basic idea can be illustrated using an example from the empirical setting, provided by the Engine & Machinery industry (E&M). This was an important industry in Britain at this time, and one that was connected to the cotton textile industry in Lancashire, as well as the wool textile industry in Yorkshire, through all three of Marshall's channels. Marshall himself used the textile and engineering industries to illustrate the possibility of labor market pooling benefits.[5] There is also evidence suggesting that textile machine makers learned from the nearby textile producers that they supplied. Engine and machine makers in Lancashire and Yorkshire competed, both to supply customers in these locations as well as in the important export market. The data show that the E&M industry had a similar growth path in the two locations prior to the shock, but that E&M firms in Yorkshire towns gained an advantage relative to Lancashire producers in the following decades, allowing them to expand employment more rapidly. This suggests that the recession in the cotton textile industry had persistent impacts on distribution of the E&M industry across locations.

The empirical strategy used to test this hypothesis involves using panel data with two cross-sectional dimensions, allowing me to compare impacts across time (pre- vs. post-shock periods), locations (towns with higher vs. lower shock intensity), and industries (more vs. less related to cotton textiles). The primary data are drawn from the British Census of Production, which were gathered from original sources. These data provide employment disaggregated into 171 industry groups, spanning nearly the entire private sector economy, available for every ten years from 1851-1891. Thus, I have multiple observations in both the pre- and post-shock period, and I am able to observe effects up to 25 years after the end of the recession. These data are available for 11 principal towns, 6 in Lancashire, and 5 in Yorkshire, providing the geographic dimension of the analysis. Additional data from local Poor Law boards, which were the primary source of funds for unemployed workers during this period, allow me to measure the severity of the shock in each town ("shock intensity") by looking at the increase in unemployed workers during the shock period. Not surprisingly, the share of each town's employment made up of cotton textile workers is a good predictor of the shock intensity in each location. Using this fact, I strengthen the identification strategy by using the share of each towns total employment that is in cotton textiles, in 1851, as an instrument for shock intensity. This approach addresses the concern that the increase in unemployed workers in each town during the shock period might

[5] Marshall (1920) (p. 226).

also be related to other localized changes that occurred at the same time as the Civil War.

An important input into the analysis is a measure of the pattern of connections between the cotton textile industry and other industries. Two measures are used. The first is based on the degree to which each industry is geographically coagglomerated with the cotton textile industry, following work by Ellison & Glaeser (1997). Ellison *et al.* (2010) show that this measure is related to measures of input-output linkages, labor market pooling potential, and technology spillovers. The second measure is an intermediate goods input-output matrix based on Thomas (1987).

The results suggest that industries more closely related to the cotton textile industry, based on the geographic coagglomeration measure, suffered lower employment and employment growth, in more severely affected towns, in the post shock period. The impacts are estimated while controlling for aggregate industry-level and town-level shocks in each year, as well as time-invariant industry-location factors. The impact of the shock on employment and employment growth continues to appear through the 1881-1891 period. The implication is that inter-industry connections can play an important role in affecting the geographic location of economic activity across locations. Moreover, temporary changes in the availability of these connections appear to have the potential to generate long-lasting effects. There appear to be no persistent effects related to the intermediate goods input-output matrix, suggesting that other types of inter-industry connections are driving the effects I observe.

This project is related to several existing strands of literature. One set of related literature studies whether temporary shocks have long-term impacts on the geographic location of economic activity, in order to test economic geography models that predict multiple equilibria in the location of economic activity.[6] Most studies focus on the impact of temporary shocks caused by war on city size.[7] Only two studies, Davis & Weinstein (2008) and Redding *et al.* (2011), consider the impact of a temporary shock

[6] See, e.g., Krugman (1991), Krugman & Venables (1995), Fujita *et al.* (1999).

[7] These include Davis & Weinstein (2002), Brakman *et al.* (2004), Bosker *et al.* (2007), Bosker *et al.* (2008b), and Bosker *et al.* (2008a). In related work, Miguel & Roland (2006) consider the impact of bombing in Vietnam on welfare outcomes and find no evidence of persistent impacts. Bleakley & Lin (2010) consider the role of historic portage locations in determining the location of economic activity today. Their results are consistent with a model of multiple equilibria and path dependence.

on the location of industries, and these deliver mixed results.[8] This study extends previous work by (1) considering the role of inter-industry connections in generating long-term impacts and (2) using data that are more detailed and comprehensive.[9] The results of this study are consistent with the existence of multiple equilibria in the geographic location of economic activity, providing support for economic geography models predicting multiple equilibria.

This paper is related to studies investigating the localized impact of trade. Studies by Kovak (2011), and Autor *et al.* (2012) look at the impact of trade liberalization on local and regional labor markets operating through the pre-reform local industry composition.[10] My study differs in two respects from previous work on trade and local labor markets. First, previous studies focus on the direct impact of trade on each industry, while I am concerned with how this impact is transmitted between industries. Second, the existing studies in this literature all focus on a permanent change in trade due to liberalization. In contrast, I focus on a temporary trade shock and consider whether such a shock, acting through inter-industry connections, can generate long-term impacts.

Finally, because I study the textile industry in 19th century Britain, there is a natural connection to the debate over the sources of the Industrial Revolution. In particular, there is disagreement over the importance of trade in generating British economic growth.[11] A key question is the extent to which the growth of trade in textiles during the Industrial Revolution impacted engine and machinery producers, driving them to improve technology, and thus contributing to Britain's economic growth. This argument has been made by Allen (2009) and others. Because I find

[8] Davis & Weinstein (2008) study the effect of the WWII bombing of Japanese cities on the location of eight highly aggregated industrial sectors (e.g., machinery, metals) and find no evidence of persistent effects. In contrast, Redding *et al.* (2011) study the impact of the division of Germany following WWII on one particular industry, airport hubs, and find evidence of a persistent effect.

[9] For example, this study considers 171 industry groups, while Davis & Weinstein (2008) consider only eight aggregated industrial sectors and Redding *et al.* (2011) consider only one, airport hubs.

[10] Other related studies in this area include Chiquiar (2008) and Topalova (2010).

[11] Authors such as Deane & Cole (1967) and Rostow (1960) emphasized that trade, by generating the demand which allowed the expansion of the cotton textile industry, was a key "engine of growth". Mokyr (1985) (p. 22) and McCloskey (1994) (p. 255-258) have disputed this view, arguing that trade, while helpful, did not drive productivity growth, and that gains from trade were relatively small.

evidence of important linkages between the textile and machinery industries, this study offers some support to the argument that trade in textiles had an important influence on the engine and machinery industries.[12]

The next section provides background information on the empirical setting, while Section 3 describes the data. Section 4 studies the impact on one industry, Engine & Machine Manufacturing. The empirical analysis is presented in Section 5, while Section 6 concludes.

2 Empirical setting

Lancashire County, in the Northwest of England, was the heart of the British cotton textile industry from the end of the 18th century and the cradle of the Industrial Revolution.[13] Lancashire's main commercial city, Manchester, became synonymous with the cotton textile trade, and the main port, Liverpool, served as the center of the world's raw cotton market. Yorkshire, the large and historically important county just east of Lancashire, had followed Lancashire's lead in industrialization and was similar to Lancashire in many respects. This study focuses only on the West Riding area of Yorkshire, which is the main industrial area of the county.[14] Figure 1 shows the location of these counties in England (left panel) and highlights the principal towns (right panel), over which the analysis will be conducted. While Lancashire was somewhat larger than Yorkshire, in terms of population, than Yorkshire, during the study period the two counties followed similar population growth paths.[15] Lancashire and Yorkshire also had similar industrial structures. For example, a comparison of employment shares by industry in Lancashire, Yorkshire, and London shows that Lancashire and Yorkshire were far more similar to one another than either of them were to London. When I rank industries by their employment shares in each area, the correlation between the rankings in Lancashire and Yorkshire is 0.75, between

[12]This argument is made for industrialization more generally by Ciccone (2002).

[13]For the purposes of this study, Cheshire, a smaller cotton textile producing county just south of Lancashire, is treated as part of Lancashire.

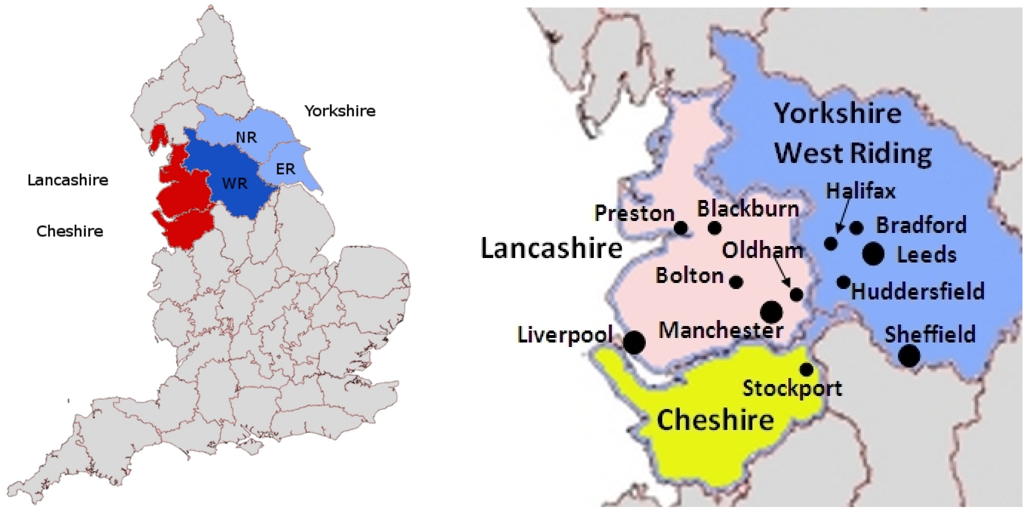
[14]This practice is common for historians studying Yorkshire during this period.

[15]Graph available in the Appendix.

Lancashire and London is 0.63, and between London and Yorkshire is 0.5.[16]

Figure 1: Maps of the study area

English Counties in 1851 Northwestern England and the West Riding



Yorkshire: "NR" is North Riding, "WR" is West Riding, "ER" is East Riding.

However, there was one key difference between Lancashire and Yorkshire. While Lancashire produced cotton textiles, producers in Yorkshire concentrated on wool textile goods (woolen and worsted), industries with a long history in the area. Table 1 describes total private employment as well as employment in the cotton and woolen/worsted industries in Lancashire and Yorkshire, in 1851, the beginning of the study period. Cotton textile employment made up over 29% of private sector employment in Lancashire, but only 4% in Yorkshire, while woolen/worsted employment made up 1% of private sector employment in Lancashire but over 30% of employment in Yorkshire.[17] Once the cotton and wool textile industries are dropped, Lancashire and Yorkshire appear even more economically similar. The industry employment

[16] A scatter plot comparing employment by industry in Lancashire and Yorkshire is available in the Appendix.

[17] In 1861, just before the onset of the shock, 85% of cotton textile manufacturing workers in England and Wales were located in Lancashire, while 72% of all of the woolen textile manufacturing workers, and 90% of worsted textile workers, were located in Yorkshire.

rank correlation becomes 0.82 between Lancashire and Yorkshire, while it is only 0.71 between Lancashire and London and only 0.54 between Yorkshire and London.

Table 1: Employment in Cotton and Wool-based Textiles – 1851

	Lancashire		**Yorkshire**	
Total Workers	1,052,154		574,820	
Cotton Textile Workers	308,243		23,116	
(as pct. of total workers)	29.30	%	4.02	%
Wool Textile Workers	11,354		174,556	
(as pct. of total workers)	1.08	%	30.37	%

Author's calculations from British Census data. Wool includes both woolen and worsted workers. Lancashire values include Cheshire. Yorkshire values are for the West Riding only.

Despite using different input materials, the cotton and woolen/worsted textile industries were largely similar. For instance, they shared the same three basic production stages. Stage one involved spinning the raw input into yarn. In the second stage, yarn was woven into fabric, while in the final stage the fabric was finished, which often included bleaching, dying, and printing. As a result of this similarity, many technologies developed for one of the industries were also adapted to work in the other. For example, spinning and weaving machines first developed for cotton were modified for use in wool and other textile production.[18] Moreover, as these industries had grown to prominence, first for cotton in Lancashire and later for woolen/worsted in Yorkshire, a large number of subsidiary trades had grown up around them. These related industries included textile machinery producers, chemical manufacturers to produce dyes and bleaches, engineering firms to produce the steam engines that powered the plants, and other textile industries that took advantage of the technological innovations made in the cotton textile industry.[19]

[18] See Catling (1986) (ch. 8) and Jenkins & Ponting (1987).

[19] Farnie (2004) provides a thorough discussion of the ancillary industries. See also Timmins (1998).

2.1 Impact of the U.S. Civil War

Prior to 1861, most of the raw cotton used in England's textile mills was grown in the Southern U.S. The onset of the U.S. Civil War in 1861 created a major disruption of raw cotton supplies.[20] While other major suppliers, such as India and Egypt, did increase production, they were unable to adjust rapidly enough to make up for the sharp fall in U.S. exports.[21] Raw cotton prices responded to the tightening of supply by rising. The left-hand panel of Figure 2 shows a dramatic spike in cotton prices starting in 1861 and continuing through 1865. Notably, the price increase in 1861 was actually fairly small, reflecting the commonly held belief at the beginning of the war that it was going to be short and cause relatively little disruption to economic activity.[22] Margins also suffered during the period, with margins on spun cotton yarn becoming negative in 1862 and not recovering pre-shock levels until 1866.[23] In response to the curtailment of supply, rising prices, and falling margins, production in the cotton textile industry fell. One of the best indicators of output in the industry is raw cotton consumption, described in the right-hand panel of Figure 2. To summarize, the onset of the U.S. Civil War reduced cotton imports, increased prices, and decreased output. The effects started in 1861, peaked in 1862-3, and persisted through 1865.[24] Figure 2 also shows that by the late 1860s, the cotton textile industry had returned to its original growth path. Its expansion then continued with only relatively minor interruptions until WWI.[25] The recovery of production in the cotton textile industry is an important feature of the story, because it suggests that any

[20] A figure showing this drop is available in the Appendix.

[21] Furthermore, the cotton produced by these other suppliers, India in particular, was often of a shorter fiber variety that was an imperfect substitute for the high quality long-fiber U.S. cotton. Often, producers were required to mix more expensive American cotton with the Indian cotton in order to make it strong enough to spin. Thus, the fall in imports is likely to understate the impact of the shock on cotton supplies. See Henderson (1969) (pp. 50-51).

[22] For example, J.C. Ollerenshaw (1870, p.112), remarked in his presentation to the Manchester Statistical Society that, "The American War commenced on April 5th, 1861, but for many months it had little effect on commerce - being generally regarded as merely temporary..."

[23] Data from Forwood (1870). See also, Helm (1869).

[24] Ollerenshaw (1870) stated that,"...we may consider 1862-5 as the years during which the effect of the American war were really experienced," adding later that,"The year 1866 is to be regarded as an exceptional year [for cotton manufacturers], equally with 1861. The war was over but prices had fallen only 1d to 1.5d per lb."

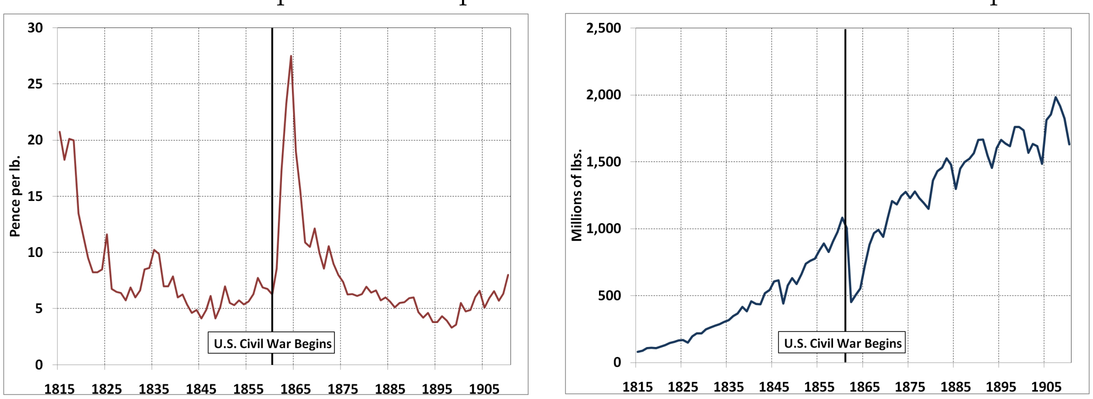
[25] Lazonick (1990) p. 138.

long-term effect that the shock had on related industries had its roots in the shock period, rather than in persistent changes in the size of the cotton textile industry.[26] It is worth noting that, while the output in the cotton textile industry rebounded rapidly following the shock, there were some persistent underlying changes, such as a shift away from U.S. cotton towards cotton from alternative suppliers. Implicit in my analysis is the assumption that it is the overall size of the cotton textile industry that is the key to its impact on related industries.

Figure 2: British benchmark cotton price and domestic cotton consumption 1815-1910

Benchmark cotton price in Liverpool

Domestic raw cotton consumption



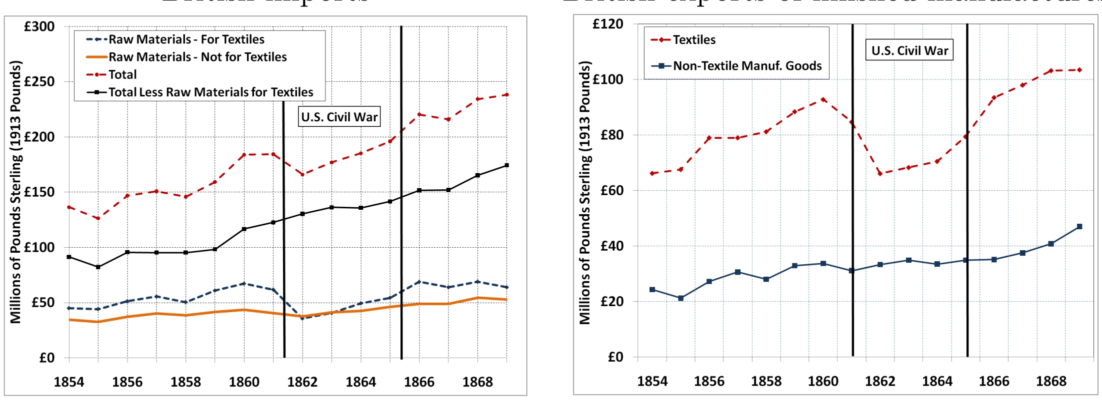
Data from Mitchell & Deane (1962). Price data is for the benchmark variety of U.S. cotton, but varieties from other locations show a similar increase during this period. Domestic raw cotton consumption is the best available measure of industry production.

[26]It is worth noting that the impact of the cotton shortage on manufacturers and traders in cotton textiles was more complex than it appears from the foregoing graphs. A number of manufacturers and traders made enormous profits at the beginning of the shock period, by selling stocks of cotton goods or raw cotton at much higher prices. However, later in the shock period manufacturers often found their resources severely strained (See Henderson (1969) (pp. 19-20)). For the rest of England, the early 1860s was generally a period of prosperity, though there were financial crises in 1864 and 1866 as a result of a decline in English gold reserves. This loss of reserves was due in part to a switch from purchasing raw cotton from American in exchange for manufactured goods to purchasing from India, Egypt, or Brazil, where goods were generally purchased with gold or silver. Importantly though, these financial crises affected England as a whole, and should therefore not generated differential impacts between Lancashire and Yorkshire, except to the extent that Lancashire banks and firms were more vulnerable due to the effects of the shock. The late 1860s, on the other hand, was a period of poor economic performance throughout England, with numerous bankruptcies among financial, commercial, railway, and manufacturing firms, a hangover from the earlier financial crises.

To argue that the U.S. Civil War created a shock that was primarily industry-specific, I look for evidence of other large direct effects of the war. I would expect any such effects to occur either through import or export channels. However, Figure 3 shows British import data from Mitchell (1988) which suggest that, once raw material for textiles are removed, British imports suffered no noticeable effect from the U.S. Civil War. Similarly, once textile exports are excluded, British exports also show no negative effects.[27] One concern may be that the areas I study were directly affected by the U.S. Civil War through armament industries. However, none of the three armaments categories included in the data, "Guns," "Ordinance," and "Ships," make up more than 0.2% of employment in any of towns included in this study, during the study period, with the exception of Liverpool, which is not included in the analysis for this reason.[28]

Figure 3: British imports and exports 1851-1869

British imports British exports of finished manufactures



Data from Mitchell (1988).

Unlike cotton, the woolen and worsted industries show little effect from the shock.[29] It is not surprising that imports of raw wool are unaffected, since most of these imports come from Spain, Australia, South Africa, or South America. While

[27] Graphs of British import and export data are available in the Appendix.

[28] Shipbuilding made up roughly 2-4% of employment in Liverpool during the study period, and Liverpool was active in providing ships used in the Civil War.

[29] Data from Mitchell & Deane (1962). Graphs are available in the Appendix.

there was some effect on wool textile exports to the U.S., this was made up for by an increase in exports to European markets during the period, particularly to France following a new trade agreement in 1860, and through increased demand for military woolens.[30]

Given that I observe a strong negative shock to the cotton textile industry but little direct effect on the woolen and worsted industries, I expect the direct effects to be much stronger in Lancashire than in Yorkshire. This is confirmed by Figure 4, which shows the number of able-bodied workers seeking relief from local Poor Law Boards as a fraction of the total 1861 population, in Lancashire and Yorkshire, over the shock period. These Poor Law Boards were the main apparatus through which relief was provided to paupers and the unemployed in England during this period.[31]

Additional evidence suggests that the shock also led to firm bankruptcy and migration from Lancashire to Yorkshire. Bankruptcy data collected from the London Gazette, described in greater detail in the Appendix, show that the number of bankruptcies by firms in the cotton industry was unusually high during the 1861-1865 period, while this was not the case for those in the wool industry. There is also some evidence that the level of bankruptcies increased more in Lancashire than in Yorkshire during this period.

It is possible to track migration between the counties in a rough way using census data on people born in each county that were residing in the other county. These data show that between 1861 and 1871 there was a net flow of just under 20,000 people from Lancashire into Yorkshire, which represents around 1% of Yorkshire's 1861 population.[32] In contrast, in every other ten-year period between 1851 and 1891

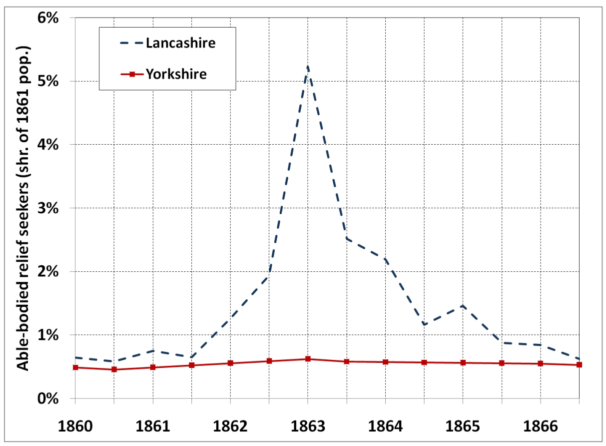
[30]Helm (1869) states, "in some of our foreign markets, linen and woolen goods have, as at home, taken the place of cotton." See also Jenkins & Ponting (1987) (p. 157-163) for a broad discussion of the effect of the U.S. Civil War on wool and worsted textiles. While the U.S. imposed an additional tariff on wool textile imports under The Morrill Tariff Act of 1861, wool textile exports to the United States rose steadily during the 1860's (Jenkins & Ponting (1987) p. 157-163) due to weak competition from domestic suppliers and the need for heavy woolen goods for military uniforms and supplies.

[31]Southall (1991) shows that Lancashire had the highest rate of pauperage of any English county in 1863, with 10.3 percent of the population receiving Poor Law Relief, while the West Riding was among the lowest. A similar pattern holds when Southall looks only at able-bodied relief seekers. In contrast, in other cyclical downturns occurring during the study period, such as those 1868 and 1879, Southall finds that relief rates in Lancashire and Yorkshire were similar.

[32]Specifically, this is the change in the number of people in Yorkshire who were born in Lancashire

there are net flows of greater than 10,000 people from Yorkshire into Lancashire, commensurate with Lancashire's somewhat faster rate of economic growth. Hanlon (2012) shows that the Civil War also impacted the rate and direction of technological progress in Britain during this period.

Figure 4: Able-bodied relief-seekers as a share of 1861 population



Data from Southall *et al.* (1998). The available data are for several of the major districts within each county, including all of those used in the analysis, but they do not cover the entire county.

To summarize, while the U.S. Civil War generated an enormous negative shock to cotton textiles, a shock that fell heavily on Lancashire, it appears that other direct effects on the British economy were of limited size. In contrast to the experience of Lancashire, Yorkshire's mainstay wool textile industry shows little effect from the shock, and may have actually benefited somewhat from substitution away from higher priced cotton textiles. It is this large differential impact that is exploited in this study in order to pinpoint the effects of the shock on those industries that were related to cotton textiles.

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3 Data

The primary database used in this study is drawn from the the British Census of Population. These decennial censuses are the best available source of information on the structure of the British economy over the period of this study.[33] The data are available for every ten years starting in 1851. In 1861, the data were collected early in the year, while the U.S. Civil War, which started in April of 1861, initially had little impact, since it was expected to be short and to cause relatively little disruption. As a result, there is little chance that the 1861 data were affected by the war. Thus, I have two observations prior to the Civil War and three observations after the war, covering 25 years following the end of the conflict. For each census, occupation data was collected from respondents by trained registrars, and each census report presents summaries of employment by occupational category.[34] The number of occupational categories in these reports varies somewhat over the period studied, with a high of 478 categories in 1861 and a low of 348 in 1891.

One feature of these occupational categories is that they generally closely correspond to industries. For example, there are occupational categories such as "Cotton textile manufacturer," "Chair maker," and "Nail manufacturer". This feature allows me to treat occupational categories as industries. Over the four decades covered by this study, some adjustments were made to the reported occupational categories. Linking these categories over time was a time-consuming task that eventually yielded occupations gathered into 234 occupational groups (hereafter, just "groups" or "industries") of which 204 groups are available for all years.[35] Of these, 171 private sector occupational categories are used in the analysis.[36]

[33] See Lee (1979) p. 3.

[34] Woolard (1999) compares these summary tables to the original enumerators books from the Isle of Man in 1881 and finds that "the original process of classification was remarkably accurate in light of the rules applied" (p. 29), particularly in the manufacturing and industrial categories.

[35] Scholars familiar with these data have noted that it is nearly impossible to perfectly match occupational categories over time due to changes in occupational classifications (see, e.g, Lee (1979)). Even within the aggregated industry groups that were constructed for this project, it is sometimes not the case that employment values are comparable over time. However, the differences-in-differences approach used in this study relies on comparisons across locations within years, so the results should be robust to most changes in occupational classifications.

[36] These 171 industries exclude 6 cotton based industries as well as government occupations and occupations that do not correspond to industries, such as "Labourer."

Data are available at three levels of geographic specificity. The most specific is the town level, for towns with populations over 50,000. The main analysis takes advantage of 11 towns for which consistent data can be obtained for 1851-1891.[37] Six of these towns are located in Lancashire and five are in Yorkshire. Data are also available at the district level. These districts are larger than towns and data is available for the entire area of the two counties, but only for 1851-1861. Data are also available at the county level.

The towns used in the analysis are listed in Table 2, together with town population, a measure of the intensity of the shock in each location based on the increase in relief seekers as a share of the 1861 population, and the share of cotton textile employment in each town in 1851. The primary measure of the severity of the shock in each town will be the percentage point increase in able-bodied workers seeking relief over the shock period, based on data from local Poor Law Boards, shown in the fourth column of Table 2. I will also apply an instrument for the shock severity measure, for reasons discussed later. The instrument will be the share of cotton textile employment in total employment in each town in 1851, shown in the last column of Table 2.

Table 2 reveals significant variation in cotton employment and the intensity of the shock across towns. Even within Lancashire, there is variation in the impact of the shock, despite the fact that all towns were major cotton textile centers. Contemporary reports suggest that some of this variation was due to local specialization in different product categories (e.g., heavy vs. fine cotton fabrics) or stages of the production process (e.g., spinning vs. weaving), which were impacted differently by the shortage of raw cotton.[38] Still, a casual glance at the last two columns of Table 2 suggests that those towns in which cotton textiles made up a significant share of production in 1851 tend to have experienced a more intense shock effect. This relationship can also be tested more formally; regression results are presented in Table 3. These results indicate that 1851 cotton textile employment share is a strong instrument for the severity of the shock in each town.

[37] Details related to the construction of the database are available in the Appendix.

[38] See Arnold (1864) (p. 102) and Henderson (1969) (p. 2). A map showing the distribution of cotton textile manufacturing activities across Lancashire towns is available in the Appendix.

Table 2: Towns used in the analysis

County	**Town**	**1861 Pop.**	**Increase in relief seekers/1861 pop.**	**Cotton emp. /1851 pop.**
Lancashire	Blackburn	63,126	7.75%	34.00%
	Bolton	70,395	1.55%	22.59%
	Manchester	460,428	8.96%	11.63%
	Oldham	94,344	3.59%	5.01%
	Preston	82,985	9.39%	25.12%
	Stockport*	54,681	3.70%	12.63%
Yorkshire	Bradford	106,218	-0.12%	0.58%
	Halifax	37,014	0.29%	0.71%
	Huddersfield	34,877	0.32%	1.28%
	Leeds	207,165	0.34%	0.06%
	Sheffield	185,172	0.85%	0.04%

* Stockport in Cheshire is treated as part of Lancashire in this study. The population and employment data are from the British Census, while the increase in relief seekers is based on Poor Law Board data from Southall *et al.* (1998).

Table 3: Relationship between cotton textile employment and shock intensity

	Shock intensity measure: (Increase in relief seekers/ 1861 pop.)
Cotton textile employment share in 1851	0.714**
	(0.234)
Constant	Yes
Observations	11
R^2	0.509

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

While the data set spans 171 industries and 11 towns, not all industries have positive employment in all towns in all years. Because I work with the log of employment, location-industries with no employment will result in missing entries. In the analysis, I include only location-industries that have positive employment levels for all five years. The result is an unbalanced panel with 1,543 complete location-industries. In essence, this analysis will be on the intensive margin of employment, i.e., changes in employment levels in industries present in a location, while ignoring the extensive margin, i.e., industries emerging or disappearing in a location. This makes sense given that my focus is on the role of inter-industry spillovers, which presumably exist primarily when both industries are present in a location.

3.1 Industry relatedness

One important input into the analysis is a measure of relatedness between the cotton textile industry and other industries in the economy. Two approaches are taken to measure the pattern of relatedness. The first uses the British Census data to construct a relatedness measure based on the geographic coagglomeration of industries. This measure is inspired by Ellison & Glaeser (1997) as well as Ellison *et al.* (2010), who find that geographic coagglomeration patterns are correlated with measures of technological spillovers, occupational similarity, and input-output flows.[39] Thus, the advantage of this measure is that it may reflect many forms of relatedness, though this comes at the cost of not being able to identify the particular types of industry connections that matter the most. Geographic coagglomeration is measured for each pair of industries and reflects the propensity of the two industries to concentrate production in the same location, where concentration implies that the size of the industry is in excess of the size that would be predicted given the location's overall size (population). Specifics of the calculation of the coagglomeration measure are available in the Appendix.

It is important to note that the geographic coagglomeration measure is calculated using the district-level census data, *which are different from the town-level data used as the primary outcome variable.* The district-level data are significantly more geographically comprehensive than the town-level data, giving me more regions to work with (71 districts vs. 11 towns). These data are for Lancashire county, but when calculating the coagglomeration measure I drop all of the districts containing towns which are used in the main (town-level) analysis. This ensures that the results I observe are not driven by the particular pattern of coagglomeration in the towns, but

[39]One critique of this approach is Helsley & Strange (2010), who show that coagglomeration patterns across locations may be inefficient, which may weaken the extent to which the coagglomeration reflects the underlying pattern of connections between industries. This should, if anything, cause Ellison *et al.* (2010) to understate the strength of the relationship between their measures of inter-industry connections and coagglomeration patterns.

rather by the underlying pattern of connections between industries.

One way to check the reasonableness of the geographic coagglomeration relatedness measure is to consider the least and most related industries.[40] At the top of the related list is cotton textile production, followed by weaving (second) and cotton finishing (fourth). Other textile and apparel industries, such as woolen, worsted, and thread manufacturing, and hat making, are also among the top 15 most related. This may reflect technological spillovers, labor market pooling, or other forms of inter-industry connections. The tenth most related industry is paper manufacturing, which may seem odd at first, but an important input for this industry at the time was waste cotton. The eleventh most related industry, coal mining, produced the second most important material input for the cotton textile industry. Engine and machine makers, an industry discussed in more detail in Section 4, ranks fifteenth. Toll collecting and road construction also rank highly, reflecting the importance of road transport in the cotton districts. Among the fifteen least coagglomerated industries, there are none that one would naturally expect to be related to cotton textiles. Examples include ship transport, sugar refining, cooper, lodging-house keeper, and tobacconist. Overall, it appears that coagglomeration is providing a reasonable measure of relatedness between industries.[41]

The second measure of relatedness is based on an input-output matrix for *intermediate goods*. This matrix is based on one constructed by Thomas (1987), and divides the economy into 42 industries.[42] The primary source used by Thomas to construct his input-output matrix was the 1907 Census of Production, Britain's first industrial census, though he also drew on a wealth of supplementary information. Because this input-output matrix was constructed using data from after the study period, there is some worry that input-output relationships may have changed between the beginning of the study period and the 1907 Census of Production. One way to test for such changes is to compare this input-output matrix to a less detailed matrix constructed

[40]A table showing the most and least coagglomerated industries is available in the Appendix.

[41]A coagglomeration measure of relatedness to the wool textile industry, calculated using data from Yorkshire, gives relatedness patterns that are fairly similar to that observed for cotton in Lancashire. The correlation between these two coagglomeration measures is 0.3, including the cotton, woolen, and worsted textile manufacturing and related industries.

[42]Details of the adjustments made to the original Thomas (1987) input-output matrix are available in the Appendix.

by Horrell *et al.* (1994) for 1841, which divides the economy into 17 categories. Once the categories in these matrices are matched, I find that the correlation between their entries is high ($> .96$), giving me confidence that this input-output matrix is relevant for the period covered by this study.

4 An Example: Engine & Machine Makers

In order to illustrate the patterns that I am interested in, this section explores the impact of the shock on one related industry, "Engine & Machine Makers" (E&M), in some detail.[43] There are two reasons to give the E&M industry special attention. First, a number of scholars have argued that this industry played a central role in the Industrial Revolution, and in Britain's economic success throughout the 19th century.[44] Second, this industry appears to be closely related to the cotton textile industry in Lancashire, and also to the woolen and worsted industries in Yorkshire.[45] The coagglomeration relatedness measure indicates a high level of relatedness between textile manufacturing and E&M. According to this measure, E&M is the 11th most related industry to cotton textiles in Lancashire (out of the 171 included in the analysis dataset), and the 26th most-related to wool textiles in Yorkshire. The intermediate goods input-output matrix does not show significant flows between these industries, since the E&M industry primarily produced capital goods.

Connections between the E&M and cotton textile producers likely took multiple forms. The most obvious connection was direct backward demand linkages from textile producers to the firms supplying their machinery, at least for a subset of E&M

[43]Other highly related industries display similar patterns to those described for the E&M industry in this section. This includes "Fuller," "Worsted Manufacturing," "Dying and Calendering," "Paper Manufacture," "Stone Worker," "Railroad Construction," "Brick Making," "Patternmakers, Typesetter, and Draughtsman," and "Mason," all of which rank among the top twenty most related industries based on the coagglomeration measure.

[44]For example, Allen (2009) argues that "the great achievement of the British Industrial Revolution was, in fact, the creation of the first large engineering industry that could mass-produce productivity-raising machinery."

[45]Farnie (2004) writes that "Textile engineering became the most important of all the ancillary trades [to cotton textiles]. Its light engineering section supplied spinning machines and looms and a whole succession of related equipment, while its heavy engineering industry supplied steam engines, boilers, and mechanical stokers."

firms. Two-way knowledge and technology flows between these industries may have also been important, though evidence of such flows is necessarily sparse. One indication of their importance is the fact that machinery firms often specialized in machinery catered to the needs of producers in their local area. For example, Bolton machine makers dominated the market for machinery to spin fine thread counts, which was mainly produced in the Bolton area, while Oldham producers were dominant in the machinery for spinning of heavier thread counts, where Oldham producers dominated production.[46] Given the relatively close proximity of these locations, there seem to be few reasons, other than knowledge flows between textile and E&M producers, that explain this specialization pattern. Furthermore, it is well documented that operators in the textile mills were active in "tweaking" their machines, to the point where, for example, "no two pairs of [spinning] mules worked in precisely the same way."[47] It seems reasonable to expect that productivity advances made through such tweaking would eventually be incorporated by local machine producers. The textile and engineering industries may have also been linked through labor market connections. Marshall (1920) (p. 226) suggests that textile firms located near E&M firms (or vice-versa) because these industries used complementary sets of labor.[48]

The pattern of growth of the E&M industry across towns over the study period is explored in Figure 5. The left-hand panel of this figure presents the sum of log employment for towns in Lancashire (high shock intensity) compared to the sum over towns in Yorkshire (low shock intensity).[49] The right-hand panel presents the sum of

[46]See Catling (1986) (ch. 7).

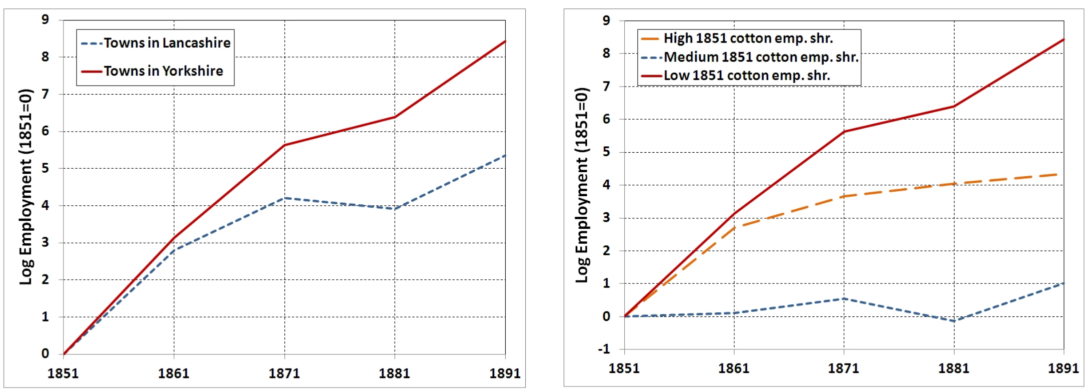
[47]Lazonick (1990) (p. 96).

[48]Textile production employed many women and children, while E&M firms employed almost exclusively adult males. Marshall (1920) argued that by co-locating, these firms could pay lower wages and still achieve similar total household incomes levels. Note that this is the opposite of how most economists think of the labor market pooling effect today, which involves benefits to firms employing similar labor forces through co-locating. Marshall acknowledged both of these potential benefits, but less attention has been paid to the benefits of co-location for industries employing different labor forces.

[49]Graphs showing the sum of log employment are shown rather than those showing the log of the sum of employment across towns because the former reduces the influence of outlier towns in the graph and also because this corresponds more directly to the econometric methodology. The main outlier is Oldham, which was the home of the most dominant engineering firm over the period, Platt Bros. of Oldham, which does not appear to have suffered as much from the shock, perhaps due to the benefits of economies of scale or market power.

log employment in towns, where the towns have been grouped based on the share of their employment in cotton textiles in 1851, my instrument for the intensity of the shock.[50] These figures suggest that the shock led to a slowdown in the growth of the E&M industries in locations in which cotton textiles were initially more important, which tended to be the locations that were more severely impacted by the shock. While the increase in log employment was similar in towns with high and low cotton textile employment shares prior to 1861, there was divergence in 1871-1891, with the towns in which cotton textiles were less important gaining a relative advantage in the E&M industry.

Figure 5: E&M Industry employment by location



Based on British Census occupations classified into the E&M group.

Given the available data, it is not possible to pinpoint which types of inter-industry connections are driving the observed effects. However, given that I observe effects that persist several decades after the end of the cotton shortage and the recovery of the cotton textile industry, it is clear that these effects cannot be driven by contemporaneous demand linkages alone. Rather, the appearance of the persistent divergence following the shock suggests that the temporary recession in cotton textile production was transmitted through inter-industry connections and generated long-lasting impacts on the relative productivity of E&M firms in more severely affected locations.

[50]The groups are: high – Blackburn, Bolton, and Preston; medium – Manchester, Oldham, and Stockport; low – Bradford, Halifax, Huddersfield, Leeds, Sheffield.

5 Econometric analysis

The basic hypothesis tested in this section is that a shock to one industry can negatively impact other related industries in the same location, and that the negative impact of this loss of spillovers can affect related industry employment in a persistent way. This intuition is motivated by a Ricardian trade model, available in the Appendix, in which technological progress occurs through learning-by-doing spillovers within and between industries. Though I test this hypothesis in a reduced-form way, the empirical specification is closely related to this theory.

The impact of the shock on some industry i in location l will depend on the extent to which industry i is related to the cotton textile industry, R_i, and the severity of the shock in location l, V_l. Thus, the key explanatory variable will be the interaction of these two terms with an indicator variable for the post-shock period. The basic regression specification is,

$$ln(L_{ilt}) = \beta_0 + \beta_1(R_i \times V_l \times POST_t) + \theta_{it} + \psi_{lt} + \xi_{il} + \epsilon_{ilt}, \tag{1}$$

where L_{ilt} is employment in industry i in location l and period t and $POST_t$ is an indicator variable for the post-shock period (1871-1891). The model includes controls for industry-time effects, represented by θ_{it}. This will help control for factors, such as demand shifts or foreign competition, that affect an industry in all locations. I also include location-time controls, represented by ψ_{lt}. These will control for factors, such as local wage effects, that are common to all industries in a location. Finally, the model includes location-industry fixed effects, ξ_{il}, which control for factors such as natural advantages or initial scale, which are specific to each industry and location. Thus, I am estimating a fully saturated fixed-effect model.

The main coefficient of interest will be β_1. A negative β_1 coefficient estimate would suggest that the shock had a negative impact on more related industries, in more severely impacted towns, in the post-shock period.

The data used in the analysis span 171 industries, 11 towns, and 5 time periods (1851-1891) of which two are during the pre-shock period and three are in the post-shock period. These 171 industries exclude all cotton-related industries, which differ from all others in that they are directly impacted by the cotton shortage, regardless of their location. Industry relatedness, R_i, can be measured using either the coagglomeration relatedness measure or the input-output relatedness measure, and in many specifications I will include both. The basic measure for the severity of the shock in each town, V_l, is the increase in the number of able-bodied relief seekers in each town during the shock period as a share of 1861 population. In order to make the results easier to interpret, the continuous variables (shock intensity and industry relatedness) are standardized to have a mean of zero and standard deviation of one. Summary statistics for the data used in the analysis are available in the Appendix.

The key identification assumption in this regression is that there are no omitted variables that change between the pre- and post-shock time periods, that affect related industries more than unrelated industries, and that are stronger in those towns more severely hit by the shock. One potential concern is that the severity of the shock, as measured by the number of able-bodied workers seeking relief from Poor Law boards in each town, may reflect changes in the economic conditions in these towns occurring at the same time as the shock which are not driven by the shock. To strengthen the identification strategy against this concern, for each specification I will calculate results in which the employment share of cotton textile production in 1851 in each location is used as an IV for the severity of the shock (interacted with the other terms). The intuition behind using this as an instrument is that it is unlikely that having a larger share of cotton textile employment in 1851 would cause a change in the performance of related industries after 1861, but not before, other than through the effects of the shock. The results in Table 4 suggest that this is a strong instrument. These results correspond to the specification shown in Equation 1, but the first-stage results are similar in the other specifications.

Another potential concern is serial correlation, since I am using panel data with multiple observations in the time dimension. Bertrand *et al.* (2004) show that serial correlation issues can be important in differences-in-differences estimation, though the structure of the data used in this study, with its large cross section and relatively short time dimension, reduces this concern.[51] In order to address this concern, I cluster standard errors at the industry-location level, thus allowing for correlation in the error

[51] See also Angrist & Pischke (2009).

terms over time within a location-industry.[52] Another potential issue, pointed out by Donald & Lang (2007), is that t-statistics may suffer when the number of clustered groups is small. However, because this study uses data from a relatively large number of clustered groups, this should not be a major concern.

Table 4: First-stage regression results

	Coagglomeration	**IO**	**Both**	
	Coag. × Shock int. × POST	IO × Shock int. × POST	Coag. × Shock int. × POST	IO × Shock int. × POST
Coagglomeration × 1851 cotton emp. share × POST	0.7319*** (0.0284)		0.7319*** (0.0283)	-0.00096 (0.0087)
IO × 1851 cotton emp. share × POST		0.7387*** (0.0513)	-0.0037 (0.0389)	0.7388*** (0.0513)
Industry-location FEs	Yes	Yes	Yes	Yes
Industry-year dum.	Yes	Yes	Yes	Yes
Location-year dum.	Yes	Yes	Yes	Yes
Observations	7,715	7,715	7,715	7,715
F-statistics	664.48	207.33	342.30	103.67

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. "Coag" indicates the coagglomeration measure of each industry's relatedness to the cotton textile industry. "IO" indicates the input-output measure of each industry's relatedness to the cotton textile industry. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for the years 1871-1891.

Regression results based on Equation 1 are given in Table 5. These results are calculated using a standard fixed-effects approach at the industry-location level, for the 1,543 unique industry-locations in the data, while including a full set of industry-year and location-year indicator variables. Columns (1) and (2) calculate standard fixed-effect results using the coagglomeration and input-output relatedness measures, respectively, while both measures are included in column (3). Column (4) presents

[52] Alternatively, I may have chosen to cluster at the industry or the town level. Results, available in the Appendix, suggest that my results are robust to these alternatives.

"reduced form" results, where the share of cotton textile employment to total employment in each location is used in place of the shock severity measure based on number of relief seekers. Columns (5)-(7) present IV results in which the share of cotton textile employment to total employment in each location (interacted with the relatedness measures and time-period indicator variables) is used as an IV for the severity of the shock in each location in a Two-Stage Least Squares regression.

Table 5: Regression results for Equation 1 (fixed effects)

	FE Coag. (1)	FE IO (2)	FE Both (3)	Reduced form (4)	IV Coag (5)	IV IO (6)	IV Both (7)
Coag.	-0.0459**		-0.0464**	-0.0570***	-0.0775***		-0.0779***
× Shock Int.	(0.0195)		(0.0194)	(0.0195)	(0.0255)		(0.0253)
× POST							
IO		0.0480	0.0501*	0.0199		0.0217	0.0265
× Shock Int.		(0.0305)	(0.0304)	(0.0354)		(0.0452)	(0.0451)
× POST							
Ind-loc FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loc-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	7,715	7,715	7,715	7,715	7,715	7,715	7,715

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. "Coag" indicates the coagglomeration measure of relatedness to the cotton textile industry. "IO" indicates the input-output measure of relatedness. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for 1871-1891. The ratio (cotton textile employment/total employment) in each location in 1851 is used in place of "Shock Int." in the reduced form regression and as an instrument for "Shock Int." in the IV regressions.

The results in Table 5 suggest that log employment was negatively impacted by the shock in more related industries, based on the coagglomeration measure, in more severely affected towns. No similar negative impacts appear for those industries linked to cotton textiles through input-output connections, and the coagglomeration measure results continue to be significant when the input-output measure is included. This suggests that the negative employment impacts are driven by some channel other than direct input output linkages. In terms of magnitude, these results suggest that in a location that is one standard deviation above the mean in terms of shock severity, an industry that is one standard deviation above the mean in relatedness would suffer a relative reduction in employment of 4.6-7.8%. Put another way, the predicted impact on an industry with a relatedness measure equal to that of the Engine & Machine Makers (1.27 s.d.), in the most severely impacted town Preston (1.77 s.d.) is a relative employment reduction of 10-17% in the post-shock period relative to the average industry and location.

As an alternative to the previous specification, I allow for the impact of the shock to grow over time in the post-shock period. The simplest way to do this is to replace the $POST_t$ variable in Equation 1 with a variable that grows linearly over time in the post-shock period. I define TT_t such that $TT_{1851} = 0$, $TT_{1861} = 0$, $TT_{1871} = 1$, $TT_{1881} = 2$, and $TT_{1891} = 3$, and write,

$$ln(L_{ilt}) = \beta_0 + \beta_1(R_i \times V_l \times TT_t) + \theta_{it} + \psi_{lt} + \xi_{il} + \epsilon_{ilt}. \tag{2}$$

Regression results generated using this specification are shown in Table 6, which has the same format as Table 1. The main variable of interest is now $Coag. \times ShockInt. \times TT$. The coefficients on this term continue to be negative and strongly statistically significant, providing some evidence that the shock may have impacted the growth rate in log employment, in addition to the level.

An alternative approach to the more standard fixed-effect approach is to use first-differencing. First differencing will be more efficient when error terms follow a random walk, which seems likely in this setting. I calculate first-difference results using the following two specifications:

$$\Delta ln(L_{ilt}) = \beta_0 + \beta_1(R_i \times V_l \times T_{1871}) + \Delta\theta_{it} + \Delta\psi_{lt} + \Delta\epsilon_{ilt}, \tag{3}$$

$$\Delta ln(L_{ilt}) = \beta_0 + \beta_1(R_i \times V_l \times POST_t) + \Delta\theta_{it} + \Delta\psi_{lt} + \Delta\epsilon_{ilt}. \tag{4}$$

In Equation 3, T_{1871} is an indicator variable for the year 1871, the first post-shock year. Thus, this expression allows me to test for impact on the level of employment in related industries. In Equation 4, $POST_1$ is an indicator for the post shock period. This expression allows me to test for persistent impacts on the change in log employment in related industries. Note that these are simply the first-differenced analogs of Equations 1 and 2.

Table 6: Regression results for Equation 2 (fixed effects)

	FE Coag. (1)	FE IO (2)	FE Both (3)	Reduced form (4)	IV Coag (5)	IV IO (6)	IV Both (7)
Coag.	-0.0205**		-0.0206**	-0.0249***	-0.0341***		-0.0341***
× Shock Int.	(0.00942)		(0.00940)	(0.00903)	(0.0118)		(0.0117)
× TT							
IO		0.0156	0.0166	-0.000170		-0.00252	-0.000402
× Shock Int.		(0.0141)	(0.0140)	(0.0160)		(0.0206)	(0.0204)
× TT							
Ind-loc FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loc-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,715	7,715	7,715	7,715	7,715	7,715	7,715

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. "Coag" indicates the coagglomeration measure of relatedness to the cotton textile industry. "IO" indicates the input-output measure of relatedness. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for 1871-1891. The ratio (cotton textile employment/total employment) in each location in 1851 is used in place of "Shock Int." in the reduced form regression and as an instrument for "Shock Int." in the IV regressions.

Results for regressions based on Equation 3 are presented in Table 7, while results for regressions based on Equation 4 are presented in Table 8. In both of these specifications I find evidence that the shock had a negative impact on the growth in log employment in more related industries and more severely impacted locations in the post-shock period.

A potential concern with my estimation strategy is the possibility that there may be pre-existing trends that differ between the treated and non-treated groups. Because my data include two observations from the pre-shock period, it is possible to investigate this issue. To do so, in place of the single post-shock-period indicator variable, I introduce a set of indicator variables for each of the years after 1851 – interacted with the measures of industry relatedness and shock intensity – as the key explanatory variables. I will be concerned about pre-existing trends if these re-

Table 7: Regression results for Equation 3 (first differences)

	FE Coag. (1)	FE IO (2)	FE Both (3)	Reduced form (4)	IV Coag (5)	IV IO (6)	IV Both (7)
Coag.	-0.0357**		-0.0363**	-0.0388**	-0.0517**		-0.0529**
× Shock Int.	(0.0163)		(0.0162)	(0.0179)	(0.0230)		(0.0229)
$\times T_{1871}$							
IO		0.0573*	0.0589*	0.0639*		0.0830*	0.0863*
× Shock Int.		(0.0305)	(0.0303)	(0.0350)		(0.0439)	(0.0441)
$\times T_{1871}$							
Ind-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loc-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,172	6,172	6,172	6,172	6,172	6,172	6,172

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. "Coag" indicates the coagglomeration measure of relatedness to the cotton textile industry. "IO" indicates the input-output measure of relatedness. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for 1871-1891. The ratio (cotton textile employment/total employment) in each location in 1851 is used in place of "Shock Int." in the reduced form regression and as an instrument for "Shock Int." in the IV regressions.

Table 8: Regression results for Equation 4 (first differences)

	FE Coag. (1)	FE IO (2)	FE Both (3)	Reduced form (4)	IV Coag (5)	IV IO (6)	IV Both (7)
Coag.	-0.0217**		-0.0218**	-0.0239***	-0.0325***		-0.0326***
× Shock Int.	(0.00976)		(0.00974)	(0.00921)	(0.0118)		(0.0117)
× POST							
IO		0.0171	0.0181	0.00611		0.00607	0.00811
× Shock Int.		(0.0144)	(0.0141)	(0.0165)		(0.0210)	(0.0207)
× POST							
Ind-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loc-year dum.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,172	6,172	6,172	6,172	6,172	6,172	6,172

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. "Coag" indicates the coagglomeration measure of relatedness to the cotton textile industry. "IO" indicates the input-output measure of relatedness. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for 1871-1891. The ratio (cotton textile employment/total employment) in each location in 1851 is used in place of "Shock Int." in the reduced form regression and as an instrument for "Shock Int." in the IV regressions.

gressions provide strong evidence that those industries that were more related to the cotton textile industry, in towns more severely impacted by the shock, have negative trends in the pre-shock period. The year-by-year regression results are presented in Table 9.[53] These results show a small and statistically insignificant coefficient for the 1861 term, suggesting that pre-existing trends are not a major concern in this context. Starting in 1871, I observe strong evidence of a negative impact on employment in more related industries and more severely impacted towns, which continues through the end of the data set in 1891. This is consistent with the shock having persistent impacts. There is also some indication that these impacts grew over time, particularly over the 20 year period from 1871 to 1891.

A number of additional results, available in the Appendix, assess the robustness of the results shown above to changes in the underlying data. These show that similar results are obtained when Liverpool is not dropped from the data or when wool and other textile industries are dropped from the analysis.

I have found evidence that the temporary shock to the cotton textile industry had a long-run impact on the geographic location of related industries. Because this result differs somewhat from previous work, such as Davis & Weinstein (2008), who find no evidence that a temporary shock had long-term impacts, it is worth trying to understand what may be driving this study to generate different results. I have introduced three innovations that may be contributing to this difference: accounting for the pattern of inter-industry connections, using more detailed industry-level data, and using data that is highly localized geographically. Additional regression results, available in the Appendix, suggest that all three of these innovations are important for generating evidence of a persistent long-term negative employment effect, resulting from the shock, on more related industries in more severely impacted locations.

[53]In the IV regression results displayed in columns 4 and 5, terms interacting year indicator variables for each year after 1851 with the coagglomeration relatedness measure and the each location's 1851 cotton textile employment share are used as instruments. First-stage regression results for these regressions are available in the Appendix. These are strong instruments, with a F-statistics of 166.05 and 85.5 for the coagglomeration interaction terms in columns 4 and 5, respectively.

Table 9: Year-by-year regression results

	Coag. (1)	Both (2)	Reduced (3)	IV Coag (4)	IV Both (5)
Coag. $\times$ Shock Int. $\times$ 1861	-0.00805	-0.00804	-0.0193	-0.0269	-0.0264
	(0.0182)	(0.0182)	(0.0200)	(0.0261)	(0.0261)
Coag. $\times$ Shock Int. $\times$ 1871	-0.0436**	-0.0442**	-0.0580***	-0.0784***	-0.0791***
	(0.0201)	(0.0201)	(0.0210)	(0.0275)	(0.0274)
Coag. $\times$ Shock Int. $\times$ 1881	-0.0332	-0.0336	-0.0514**	-0.0703**	-0.0702**
	(0.0261)	(0.0261)	(0.0259)	(0.0339)	(0.0338)
Coag. $\times$ Shock Int. $\times$ 1891	-0.0728**	-0.0733**	-0.0907***	-0.124***	-0.124***
	(0.0311)	(0.0311)	(0.0303)	(0.0395)	(0.0394)
IO $\times$ Shock Int. $\times$ 1861		-0.00119	-0.0243		-0.0331
		(0.0305)	(0.0329)		(0.0422)
IO $\times$ Shock Int. $\times$ 1871		0.0561*	0.0379		0.0509
		(0.0306)	(0.0348)		(0.0449)
IO $\times$ Shock Int. $\times$ 1881		0.0442	-0.00383		-0.00554
		(0.0429)	(0.0464)		(0.0598)
IO $\times$ Shock Int. $\times$ 1891		0.0483	-0.0109		-0.0154
		(0.0426)	(0.0493)		(0.0628)
Ind-loc FEs	Yes	Yes	Yes	Yes	Yes
Ind-year dummies	Yes	Yes	Yes	Yes	Yes
Loc-year dummies	Yes	Yes	Yes	Yes	Yes
Observations	7,715	7,715	7,715	7,715	7,715
Test that the $Coag \times ShockInt. \times 1871$ coefficient differs from the $Coag \times ShockInt. \times 1861$ coefficient					
F-statistic	4.89	5.10	4.8	5.03	5.31
P-value	0.0271	0.0241	0.0286	0.025	0.0212
Test that the coefficient on the coagglomeration terms for 1871-1891 are jointly different from the $Coag \times ShockInt. \times 1861$ coefficient					
F-statistic	3.01	3.08	3.16	10.44	10.66
P-value	0.0293	0.0265	0.024	0.0152	0.0137

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. "Coag" indicates the coagglomeration measure of relatedness to the cotton textile industry. "IO" indicates the input-output measure of relatedness. "Shock Int." is the increase in able-bodied relief-seekers as a share of 1861 population in each location. "POST" is an indicator variable for 1871-1891. The ratio (cotton textile employment/total employment) in each location in 1851 is used in place of "Shock Int." in the reduced form regression and as an instrument for "Shock Int." in the IV regressions.

6 Conclusion

This project describes a large, exogenous, industry-specific shock to the 19th century British economy and shows that it affected the distribution of industries across locations up to 25 years after the end of the shock. In particular, it shows that those industries more closely related to the industry that was directly affected, cotton textiles, suffered long-term reductions in employment and employment growth, in those towns that were more severely affected by the shock. This provides causal evidence that inter-industry spillovers can transmit negative shocks with long-term effects. These effects are of significant magnitude and longevity given the transient nature of the shock considered.

These results provide further evidence that inter-industry industry connections, such as those suggested by Marshall (1890), exist and play an economically important role. In particular, they show the role that such connections can play in transmitting shocks and in influencing the location of economic activity in the long-run. What mechanism are most important in driving these effects remains an open question and an important area for future research.

While this study focuses on a large negative shock caused by exogenous factors, it seems possible that localized industrial policy interventions may be able to generate similar effects. This may provide some justification for the widespread use of these policies. Moreover, while I have studied the role of inter-industry connections in influencing the location of industries within a country, it seems plausible that similar effects can occur across countries. Thus, these results may have implications for trade policies such as infant industry protections. However, the effectiveness of such policy interventions are likely to depend crucially on knowing the pattern of connections between industries, something which is currently not well understood.

I also find evidence that temporary shocks, if large enough, can have long-lasting effects. This finding lends support to economic geography theories with multiple equilibria. One implication of this result is that, when evaluating policies that may influence the susceptibility of an economy to external shocks, the possible impact of these shocks on long-term outcomes should be considered.

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