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Abstract

I study the slow adoption of ring-spinning in Great Britain's cotton industry at the end of the 19th century, which has been used as evidence of British entrepreneurs' declining efficiency and conservatism (Musson [1959], Aldcroft, [1964], Lazonick [1981, 1981b]). To this purpose I use firm-level data from all of Lancashire's cotton firms over several years. The data are from the Worrall's Cotton Spinners' and Manufacturers' Directories for the years 1885, 1886-1887, 1890, 1894, 1902, and 1910.

First, I show that the vertical organization of the industry, with its firms specializing in spinning or weaving, did not act as an impediment to the adoption of the ring-spinning technology, as was argued by Lazonick. In particular, I show the following: i) non-integrated firms were the first to adopt rings in Great Britain; ii) the large majority of firms that adopted rings were incumbents; iii) vertically integrated firms that were spinning only either twist or weft yarn were still in existence in 1910; and iv) only a negligible number of firms changed their organizational structure upon adopting ring spinning. I also show that a large fraction of firms installed very small numbers of ring spindles upon the adoption of ring spinning, suggesting that firms were slowly adopting ring spindles to replace old mule spindles rather than transitioning over to ring spinning at a single point in time.

Then, I show that the rate at which vertically integrated firms adopted rings suddenly accelerated after 1902. I interpret this as evidence that British entrepreneurs were fully aware of the technological complementarities between rings and automatic looms. These complementarities could only be fully exploited by vertically integrated firms.

Keywords: Ring Spinning, Technology Adoption, Cotton Industry, Lancashire, Vertical Integration, Specialization.

JEL Codes: N63, L22, L67.

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1 Introduction

For decades, historians have been concerned with explaining the decline of Great Britain as the economic world leader after 1870. By the end of the 1890s, Britain had lost the industrial leadership of the world to Germany and the United States (McCloskey and Sandberg [1971]). In an influential paper, Aldcroft [1964] argued that "Britain's poor economic performance can be attributed largely to the failure of the British entrepreneur to respond to the challenge of changed condition. [...] The failure to adopt new techniques, that is new machinery and other cost-reducing innovations [...] was one of the chief reasons [...] for the decline in the rate of growth of the British economy."[1]

This paper investigates whether the decline of Great Britain can be explained, at least in part, by the ineptitude of its entrepreneurs, as was argued by Aldcroft. To address this question, I look at one industrial case that has been at the center of a highly charged and often heated exchange spread out over a number of rounds and spanning several decades: the slow adoption by the British entrepreneurs of ring-spinning in yarn production. The main reason why the adoption of ring-spinning has received so much attention is because the British cotton industry was the most important export industry in Britain throughout the 19th century.

Since the mid 1880s, the new technique of ring-spinning had become economically viable in yarn production.[2] The production of yarn was faster with ring-spinning than with mule-spinning. Furthermore, labor costs were lower. Ring-spinning was more efficient than mule-spinning: per unit of time, ring-spinning resulted in higher production at a lower labor costs. If British entrepreneurs

[1] Aldcroft [1964], p. 113 and p. 115. For a critical analysis of the full "damning catalogue" of the British entrepeneur's reasons of failure, see McCloskey and Sandberg [1971].

[2] Leunig [1996, 2001] provides a review of the cotton manufacturing process and of the differences between ring and mule spinning. He also provides a comprehensive review of the literature. Here, I present the key insights of the debate on the adoption of rings in Great Britain at the end of the 19th century.

had been profit maximizers, the indictment reads, they should have started adopting ring-spinning as soon as the early 1880s, when it became economically viable. Until 1910, however, mule-spinning continued to be heavily preferred to ring-spinning. For this reason, the slow adoption of ring-spinning has been used as evidence of British entrepreneurs' declining efficiency and conservatism (Musson [1959]).

Sandberg [1969] challenged the interpretation of the slow adoption of ring spinning as evidence of the ineptitude of the British entrepreneurs. He calculated the cost and benefits of mule versus ring-spinning, and concluded that the choice of production technique was rational. Lancashire cotton firms were adopting rings for the production of the coarser types of cotton yarn for which the ring was superior to the mule.

Lazonick [1981, 1981b] revived the hypothesis that Lancashire cotton firms were managed by inept entrepreneurs. Lazonick confirmed Sandberg's conclusions that Lancashire "businessmen performed admirably as neoclassical managers," but he also advanced the hypothesis that they "failed as entrepreneurs."[3] Lazonick showed that entrepreneurial failure was systematic across the cotton industry, and did not only involve "scattered cases of entrepreneurial success or failure."[4] The central tenet of Lazonick's argument was the following. In the last quarter of the 19th century, most of the Lancashire cotton firms were either spinning cotton or weaving yarn. Some vertically integrated firms were both spinning and weaving on the same site. Lazonick argued that the cost of shipping ring yarn was significantly higher for non-integrated firms than it was for integrated firms, while the difference was inconsequential for mule yarn. Rings spun the yarn on a heavy

[3] Lazonick [1981b], p. 37.
[4] McCloskey and Sandberg [1971], p. 99.

wooden bobbin that needed to be rewound, while mules spun yarn on small and light packages ready to be woven. For some type of yarn, the difference of the transportation costs was so large that a non-integrated firm would have never found it profitable to adopt ring spinning. Lancashire businessmen should have then vertically integrated but did not, failing to "recognize that managers from time to time (as innovating entrepreneurs), overcome 'given' constraints and on a more regular basis (as supervisors of the enterprise) alter 'given' constraints."[5] The constraint that Lancashire cotton firms did not overcome was the vertical organization of cotton production.[6]

Saxonhouse and Wright [1984] challenged Lazonick's claim that the Lancashire cotton firms did not adopt rings because of the vertical organization of the industry. First, they used data from the records of British textile machinery companies to show that the Lancashire cotton firms did not adopt an innovation (paper-tubes) that would have reduced the transportation costs associated with ring spinning.[7] They inferred that transportation costs had to be lower than what Lazonick computed, because otherwise the British firms would have adopted the innovation.[8] Second, they used the same records of British textile machinery companies to develop a cross-country comparison

[5] Lazonick [1981], p. 90.

[6] See Lazonick, pp. 396-397 [1984] for more on this. Temin [1988, page 906] has argued that the ease of access to capital made the formation of integrated concerns easier in North America. Following Temin's argument, this is equivalent to saying that if in Lancashire there had been easy access to capital, cotton firms would have chosen vertical integration over specialization. However, information at the firm-level shows that many firms were sharing power, plants, and possibly power-looms. As Gatrell [1977, page 105] wrote, in the 1820s and 1830s, credit was available to all producers in these years: "by 1835, it was claimed that 'most' new firms were being set up on borrowings of up to two-thirds of the value of buildings and machinery combined."

[7] Saxonhouse and Wright use the data from the records of British textile machinery companies to also confirm one of Lazonick's finding, which is that British cotton spinners maintained their commitment to the mule in new installations until World War I.

[8] In his reply to Saxonhouse and Wright, Lazonick [1987] made a useful distinction between twist and weft yarn, which Saxonhouse and Wright essentially accepted: paper tubes would have ensured lower transportation costs only for twist (warp) yarn, not for weft yarn. Thus, Saxonhouse and Wright's main point remained valid as far as warp yarn was concerned: Lancashire cotton firms did not adopt it to as great of an extent as they should have if transportation costs were as important as Lazonick had claimed in his previous work.

between Britain, New England, and Japan.[9] On one hand, they pointed out that New England had a vertically integrated cotton industry but never attained international competitiveness.[10] On the other hand, they highlighted the case of the Japanese cotton industry, which rapidly captured the world markets in the 1920s and 1930s while switching from mules to rings, but never wove more than 30 percent of its yarn on a vertically integrated basis.[11] Using this stark contrast between the British, Japanese and New England experiences, Saxonhouse and Wright concluded that vertical specialization was not, *per se*, an obstacle to ring adoption.

In recent work, Leunig [1996, 2001] further investigated the differences in transportation costs associated with ring and mule spinning. Leunig broke down the distribution of spinners and weavers in Lancashire and assessed how much yarn was spun and woven in each district. He constructed proxies for yarn output and weaving capacity, and identified these districts where weaving capacity exceeded total spinning output. He called these the "co-located" districts. All spinners in a "co-located" district could have sold all of their yarn to weavers within their districts. The critical point made by Leunig is that non-integrated firms in "co-located" districts could escape the problem of

[9] Saxonhouse and Wright [2009] further investigate the evolution of ring spinning at global, national and firm levels, and track adoption decisions in a large number of countries over a span of more than fifty years. The result of their investigation is a case study in global competition between contending technological paradigms.

[10] See Leunig [2003] for an analysis of productivity in the Lancashire and New England cotton spinning industries at the beginning of the 20th century.

[11] Lazonick addressed this second point made by Saxonhouse and Wright in a paper with Mass (Mass and Lazonick [1990]). Lazonick and Mass claimed that the explanation of Japan's success was in its "planned co-ordination," which dominated the "market co-ordination" of the Lancashire industry. That is, spinning-only firms as well as merchants (or trading companies) co-ordinated the vertical structure of the industry so that even though they never wove more than 30 percent of its yarn (mostly for the export trade) on a vertically integrated basis, it still acted as if it was fully vertically integrated. The crucial question here is, how do we measure the extent of vertical co-ordination? More specifically, how can we determine in some quantifiable fashion whether the Japanese cotton industry was more vertically "co-ordinated" than the British one? In contrast to the original article by Lazonick [1984], Mass and Lazonick [1990] does not provide a sharp and definitive testable hypothesis, just an interesting perspective on the differences between the Japanese and the British cotton industries at the beginning of the 20th century. For more on this, and for a more detailed discussion of the role of merchants as co-ordinating agents in the Lancashire cotton industry, see Broadberry and Marrison [2002] and Farnie [2004].

transport costs. Hence, by contrasting the ring adoption patterns of integrated and non-integrated firms in co-located districts, Leunig tested whether the vertical organization of a firm acted as a constraint in the adoption of rings. Leunig found that rings were the clear majority choice for both vertically integrated and co-located firms, whereas mules were the clear majority choice for vertically isolated firms. Leunig also concluded that vertical specialization was not *per se* an obstacle to ring adoption.

A fundamental unifying feature of the works by Sandberg, Lazonick, Saxonhouse and Wright, and Leunig is that they all use aggregate data to investigate a fundamentally firm-level issue, the adoption of ring-spinning. To be able to infer something about firm behavior from aggregate data, these authors used very clever arguments. Here, I take a different approach. Instead of relying on some very sophisticated deductive arguments, I let the data speak.

The main contribution of this paper is to use firm-level data from the entire population of Lancashire cotton firms over several years to investigate the organizational and technological choices of the cotton firms in Lancashire. The data are from the Worrall's Cotton Spinners' and Manufacturers' Directories for 1885, 1887, 1890, 1894, 1902, and 1910.[12] In practice, I collected and organized data for thousands of firms, and classified them as spinner-only, weaver-only, or vertically integrated firms. This makes it possible to directly test arguments that Lazonick used to claim that British entrepreneurs failed as entrepreneurs. I also match information from the Worrall's Directories with maps of Preston and Blackburn extracted from the Ordnance Survey, 1891-92. This allows me to

[12] Lazonick [1981] used the same data source for 1907 and 1910, but mainly at an *aggregate level.* The only *firm-level* information that Lazonick uses from the Worrall's directory concerns the 2100 ring spindles in all of Lancashire that spun weft in a non-integrated mill (Lazonick [1981], p. 98). Leunig [1996, 2001] uses data from Worrall's Directory in 1905 to argue that the adoption rates of rings to spin weft yarn were not different between vertically integrated and non-integrated firms.

check Leunig's theory of co-location using firm-level data.

First, I show that the vertical organization of the industry, with its firms specializing in spinning or weaving, did not act as an impediment to the adoption of the ring-spinning technology, as was argued by Lazonick. In particular, I show the following: i) non-integrated firms were the first to adopt rings in Great Britain; ii) the large majority of firms that adopted rings were incumbents; iii) vertically integrated firms that were spinning only either twist or weft yarn were still in existence in 1910; and iv) only a negligible number of firms changed their organizational structure upon adopting ring spinning. I also show that a large fraction of firms installed very small numbers of ring spindles upon the adoption of ring spinning, suggesting that firms were slowly adopting ring spindles to replace old mule spindles rather than transitioning over to ring spinning at a single point in time.

Then, I show that the rate at which vertically integrated firms adopted rings suddenly accelerated after 1902. This is a novel and striking finding that had not been uncovered till now. I interpret this finding as evidence that British entrepreneurs were fully aware of the technological complementarities between rings and automatic looms. These complementarities could only be fully exploited by vertically integrated firms.

The paper is organized as follows. I provide a description of the cotton manufacturing process in Section (2). The new dataset is briefly described in Section (3). Section (4) investigates how the deductive arguments used by Sandberg, Lazonick, Saxonhouse and Wright, and Leunig fare when firm-level data is used. Section (5) proposes an explanation for why vertically integrated firms started adopting rings only after 1902. Section (6) concludes.

2 A Brief Introduction to the Production of Cotton

Cotton Spinning and Weaving. The production of cotton can be summarized in four successive steps: cleaning the raw cotton;[13] "spinning", or transforming the cleaned raw cotton into yarn; "weaving" the yarn into cotton cloth; and the finishing operations, such as "bleaching", "dyeing" and "printing". In this paper I focus on the spinning and weaving processes.[14] The basic function of the spinning process is to bind the filaments together into one strand by means of twisting it, and ensure that the resulting yarn resists the strain which it will have to undergo when woven. After being twisted, the yarn is wound into a package to be shipped to weavers. These two sub-processes, twisting and winding, can either be done continuously (using rings) or intermittently (using mules). Weaving consists of combining two sets of threads, one of which is immobile (the warp or twist), and the other which moves normally to the first and fills it (the weft).[15]

Technological Progress. There are three technological periods for weaving. First, between 1800 and 1830, the hand-loom was used to produce all cloths. Often, spinning was done in factories, while weaving was either outsourced to households, or done in sheds attached to the factory. By 1830, the power-loom was perfected and could be used to weave coarse and medium cloth. Cloths

[13] Cleaning consists of loosening the mass of fibers that form the original status of the raw cotton into a clean set of individual fibres parallel to each other. This is done by passing the raw cotton through rollers, and this operation is called "carding". If the cotton is of a fine quality, an additional operation, called "combing", is performed on it, to remove fibers that are too short and ensure a parallel position for the remaining ones. Finally, the fibers are combined together ("drawing" and "roving") and attenuated so that the resulting filaments are uniform in thickness before going through the subsequent spinning process.

[14] During the cleaning process some of the cotton is wasted. Some of this waste is lost, but some is recovered through the "condenser system". Because the final product which is obtained from the condenser system is very special and different from the product obtained from the standard processes of spinning and weaving, it is not considered here. See Robson [1957] for more on this.

[15] The result of spinning was either warp or weft yarn. The first had to be stronger than the second, since it will serve as the frame of the cloth, while the weft will be used to fill the twist to form the cloth. Weft would use cotton that is 7 percent shorter than that needed for ring warp (Leunig [1996]).

that used yarn of counts of up to 60 could be woven in 1841 with power looms. Between 1850 and the 1880s, the power-loom was extended to the production of fine cloth. In 1894 the automatic loom was invented in the US, but it was adopted very slowly in Britain.

There are two technological periods in spinning. The first period goes from 1820 until the early 1880s. In these years, the self-acting mule was used by all spinners. Then in the early 1880s, the ring-frame was perfected for spinning coarse and medium cloths and was slowly adopted by British entrepreneurs.

Fineness. Cotton yarn is normally classified as coarse, medium, or fine. The unit of measure of fineness is the "hank". A hank of cotton yarn or twist always measure 840 yards. If the count of 1 is reported, this means that one hank of cotton yarn weighs one pound. If the count of 40 is reported, this means that forty hanks of cotton weigh one pound.[16] The more hanks that are needed to make one pound, the finer the yarn is. Thus, a count of 120 means that the yarn is very fine, a count of 40 means that the yarn is of medium fineness, and a count of 2 means that the yarn is very coarse.

Ring versus Mule Spinning. Ring-spinning subjected cotton to more strain: for any given count, mule spinning could use raw cotton of lesser quality relative to what ring-spinning could use. Ring spinning required a longer cotton staple and, since the price of cotton increased with length, the raw input was potentially more costly under ring-spinning. Leunig calculates the cost differentials of raw cotton between ring and mule spinning.[17] He convincingly shows that the

[16] Ure [1831], Appendix A, page 335.

[17] Leunig [1996], p. 66. Leunig's findings do not support Lazonick's, [1981. p. 103] assumption on the cost differentials between mules and rings.

premium started slightly in the range of counts 20 to 30 and increased with count spun.[18]

Rings required unskilled or semiskilled female labor, while mule spinning used highly skilled male labor. Furthermore, ring-spinning was faster. In the same amount of time, one ring spindle could produce 1.45 times more than one mule spindle.[19] Sandberg, Lazonick and Leunig concluded that, as far as labor costs were concerned, ring-spinning was cheaper than mule spinning for all counts. Leunig showed that labor cost savings increased in the count spun.[20]

Mule weft yarn was wound into packages that were lighter than the wooden bobbin needed for ring weft yarn. Sandberg showed that ring spinning increased the transportation costs of weft yarn by 200 percent. Lazonick showed that it cost as much to return bobbins as to send them, and that there was always the possibility that some or all of the bobbins would be lost or broken. The extra cost per pound of shipping ring weft would then rise by 500 percent. Transportation costs for twist yarn varied much less: Leunig finds the transport cost of shipping ring twist yarn to be larger by a value between 24 percent and 100 percent.[21]

Vertical Organization of the Industry. There were four types of firms in the industry. Each type of firm could own more than one plant.

The first two types were firms that specialized in either spinning or weaving. For example, the firm E. & W. Bolling owned four plants in Bolton in 1833, and the four of them were dedicated only to spinning. These were vertically specialized firms, or spinning-only or weaving-only firms.

Then there were firms that were vertically integrated in a strict sense: they were spinning and

[18] Normally weft yarn is of higher count than twist yarn. For example shirtings were produced with twist counts in the 20s and weft counts in the 30s (*Cotton Manufactures, Report of the Tariff Board on Schedule I of the Tariff Law*, House of Representatives, Washington, 1912).

[19] Leunig [2001].

[20] Leunig [1996], p. 66.

[21] Leunig [2001].

weaving in the same building. For example, in 1833 the firm Birley and Kirk owned a firm in Manchester where 931 spinners and 471 weavers worked. These were vertically integrated firms.

Finally, there were firms that were vertically integrated in a loose sense: they were both spinning and weaving but in two different plants. For example, the firm Hadfield and Frost owned two plants in Warrington in 1833: one plant had 143 spinners while the other plant had 192 weavers. These were vertically combined firms.[22]

There is a rich literature on the advantages and disadvantages of specialization in the production of cotton. On one hand, Farnie [1979, page 319] has argued that "by compartmentalizing technical knowledge", vertical specialization "accentuated the vertical ignorance of both spinners and manufacturers, [...] it insulated spinners from the ultimate market for woven goods, hindered them from producing the yarns best suited to specific types of cloth." Similarly, using data from the 1841 Inspector Horner's Factory Reports, Gatrell [1977] argues that if there were advantages for the firms that were spinning and weaving, then these advantages were not derived from their larger size in and of itself, but from "internal economies in the costs otherwise incurred in selling, buying, and transporting yarns." On the other hand, Jewkes [1930, page 96] argued that specialization gave firms the ability to adapt to "the changing conditions of the market and the scale of production: [...] the multiplicity of finished products and the different technique demanded for maximum efficiency in spinning and weaving firms [forced] the separation in the ownership and control of the two processes." Also, Huberman [1990] has argued that after 1850, "new firms tended to specialize in spinning or weaving because large integrated firms faced a managerial constraint [because

[22] The distinction between vertically integrated and combined firms is particularly interesting: it should provide information on whether the differences between vertically specialized firms and those that were not vertically specialized were at the plant or the firm level. I'll return to this in Section (4.1).

they were] unable to monitor and supervise their work forces effectively."[23] Saxonhouse and Wright [1984, page 518] also claimed that "the newer firms and mills were specialized and, in conjunction with highly developed markets and marketing facilities, [...] were able to exploit distinct managerial talents and abilities as well as economies of long production runs for standard counts of yarn". In this paper, I stay away from determining which of those advantages and disadvantages dominated, and I only look at the ring adoption behavior of the two organizational forms.

3 Data

The data are from the Worrall's Cotton Spinners' and Manufacturers' Directories of 1885, 1886-7, 1890, 1893-4, 1902 and 1910. These data contain information on the names of the firms, locations, and types of spindle used by cotton firms in Lancashire. They also contain information on the number of spindles (and looms) used by each firm, the fineness of the product manufactured and whether the firm spun both twist and weft yarn.

An important step in the coding of the data consists of determining the fineness of cloth. To this end, I have followed two approaches, compared their results, and then checked their consistency against each other. First I have used the "Cotton Manufactures: Report of the Tariff Board on Schedule I of the Tariff Law", Message from the President of the United States, Washington, 1912. The report presents a section that associates the range of counts for yarn to the type of cloth produced: for example, "Heavy Sheeting" is produced with twist yarn of count 12, and with weft yarn of count 16. Another example is "Shirting", which is produced with twist yarn of count 28 and weft yarn of count in the 30s. This classification does not cover all the types of clothes. When a

[23] Huberman [1990], page 683.

type of cloth is not included, I look for a firm that also produces another type of cloth that is in the book and infer the classification for the one that is not in the book. Then I used the information from the Worrall's Directories. I reasonably assumed that firms producing both yarn and cloth will choose a range of counts for yarn that can be used by their weavers to produce cloth. I have done a consistency check between the two methods and the results are perfectly consistent. The results are presented in the **Table 1**.[24]

Table 2 provides the summary statistics for the cotton firms in Lancashire in 1890. The first row gives the percentage of industry output by firm type in 1890. Spinner-only firms owned 64.4 percent of the total spindleage in 1890.[25] In 1902, the spinner-only firms controlled 71.0 percent of the spindle capacity. By 1910, they controlled 78.8 percent. Notice that this number is the same as the one reported by Lazonick.[26] Thus, spinner-only firms increased their spinning capacity over time.

The last rows of **Table 2** show that the number of spinner-only firms increased between 1890 and 1910, while the number of vertically integrated firms declined.

Just by looking at **Table 2**, it is already difficult to reconcile the dramatic increase in the number of spinner-only firms, and in their capacity of spindles, with the idea that vertical integration was

[24] In practice, to classify the product I have proceeded as follows. I have identified five classifications: very coarse ("1"), coarse/medium ("12"), medium ("2"), medium/fine ("23"), fine ("3").If a firm reports that it spins yarn of count between 0 and 20, then the firm is assigned a "1". If the firm reports a twist count between 20 and 40, then the firm is assigned a "2". If the firms reports a twist count above 40, then I assign the firm a "3". I include the upper extreme in the lower interval. For example, a count of 40 corresponds to "2". I then apply the classification to weft yarn, and assign a "1" for 0-30, a "2" for 30-50 and a "3" for counts above 50. In some cases there may be uncertainty because weft and twist are in different sections. When this occurs, I follow a conservative approach, and use the twist. Often firms produce counts that are between regions. For example, they may choose to produce yarn of count 10/30. In this case I assign the firm a count equal to "12". If a firm has very few spindles or few looms, then I take a conservative approach, and if the firm gives a very large range of counts (say 10/30), then I assign it in the lower region ("1").

[25] My numbers are unadjusted for differences in speed between rings and mules.

[26] Lazonick, [1984] p. 394.

the most efficient way to manufacture cotton. It would have taken a truly impressive degree of ineptitude on the part of the British entrepreneurs to justify these patterns in the data.

4 Did British Entrepreneurs Fail?

In this Section, I first provide new evidence on the importance of transportation costs in the cotton industry. Then I check, one by one, all of the deductive arguments used by Lazonick, and see if there are fallacies with them that can be uncovered by the firm-level data.

4.1 Transportation Costs

As discussed in the introduction, the crucial insight of Lazonick's analysis is that the transportation costs of shipping ring yarn were significantly larger than those of shipping mule yarn, and thus British entrepreneurs should have vertically integrated in order to escape the higher transportation costs of shipping ring yarn. **Table 3** shows the conclusions that can be drawn from the new calculations made by Leunig for labor and raw cotton costs, and the calculations made by Lazonick for transportation costs. The first row of **Table 3** shows that vertically integrated firms, which could escape transportation costs, should have chosen rings to produce weft and twist yarn of counts lower than 40. The second row of **Table 3** shows that non-integrated firms should have chosen rings to produce twist yarn of counts lower than 40, but should have never chosen rings to produce weft yarn.

The best place to begin the empirical analysis is to look more carefully at some evidence on the actual magnitude of transportation costs. In abstract, the transportation costs could be quite large, as Sandberg, Lazonick, and Leunig showed in their detailed analysis. The relevant issue

here is whether, in practice, the costs were actually so large. As Leunig observed, if firms were geographically close to each other then, in practice, transportation costs would be negligible. Using aggregate data, Leunig identified "co-located" districts, where weaving capacity exceeded total spinning output. Here, I take another step in this direction.

Evidence from the Ordnance Survey. I match the information from the Worrall's Cotton Spinners' and Manufacturers' Directory of 1890 with historical maps published as part of the Ordnance Survey conducted in 1891 and 1892 in Great Britain. I look at the distribution of cotton mills in the centre of two towns, Blackburn and Preston. For both of them I identify whether a cotton mill corresponds to a weaver, a spinner, or an integrated firm. Then, I identify whether the spinners or the vertically integrated firms produce both weft and twist yarn, or just one of the two.

Figure 1 looks at the case of Blackburn. We observe that firms were locating their plants (mills) close to each other and to the canal. Eanam Bridge Mill was a spinning firm, producing only weft yarns. In the adjacent building, Rose Hill Mill was an integrated firm and produced both twist and weft yarn. In the building in front, the Wharf Street Mill housed a weaver. Clearly, spinning and weaving plants were located very closely together, suggesting that the transportation costs would have been negligible.

Figure 2 shows that Blackburn was not an exception. We can count as many as ten mills in the centre of Preston. The survey shows that in Preston the vertically integrated firm Goodair John & Co. owned the Brookfield Mill and the Peel Mill. Goodair John & Co. spun only weft yarn. In the building in front of the Brookfield Mill sat the Southgate Mill, owned by the vertically integrated firm Smith Joseph. Smith Joseph spun both twist and weft yarn. Within a short distance, there

were four weavers-only, one spinner-only and another vertically integrated firm. Nothing in the data indicates whether these nine firms were in a business relationship, but vertically integrated firms were located in a district with several firms that were all closely located.

Both **Figures 1** and **2** tell the same tale. Firms of all types (spinners, weavers, and vertically integrated) were all located near each other. Ideally, one could construct maps for all districts and all firms, and could even compute the distances between mills as a measure of transportation costs. Yet the main finding would remain the same: while transportation costs were potentially large, in practice they were most likely negligible.

Firms and Plants. Another approach to show that transportation costs had to be negligible consists of looking for counter-examples. I look for vertically integrated firms that do not manufacture both weft and twist in-house. This would provide evidence that even vertically integrated firms were willing to pay the transportation costs. The driving idea is to use the distinction between plant and firm. This distinction is important here because firms often shared the same plant (here meant as a physical bulding), or one firm controlled more than one plant.[27]

The new firm-level data clarify that firms that both wove and spun might very well have been doing those two things at different plants. For example, in 1890 the firm Taylor D. & W. located in Blackburn owned $111,800$ spindles and $2,152$ looms. The firm distributed its production among six mills. **Figure 1** shows that at least one of them, the Bridge Water Mill, was not close to any of the other five mills owned by the firm. The closest mills to the Bridge Water Mill were owned by two weaver-only firms. We do not know whether the Bridge Water Mill both spun and wove or

[27] See Mokyr [2001] for a discussion on the distinction between firms and mills and for a more general analysis of the rise and fall of the factory system.

did only one of the two.[28]

In only a few exceptions is information available on how firms distributed their productions across plants. These exceptions can be used as a counter-example to Lazonick's claim that entrepreneurs should have vertically integrated in order to escape the higher transportation costs of shipping ring yarn. In the Worrall's Cotton Spinners' and Manufacturers' Directory published in 1902, the firm Halliday & Constantine owned the Dicconson Mill at Wigan where it only spun (using ring spindles) and the Upper Mills in Golborne, where it only wove. This firm was definitively not vertically integrated. Another counter-example was given by the firm Hadfield and Frost, which owned two plants in Warrington in 1833: one plant had 143 spinners while the other plant had 192 weavers. One could also construct numerous counter-examples by showing the large amount of heterogeneity in the ratio of spindles to looms at vertically integrated firms, which suggests that these firms did outsource some of the weaving or spinning to specialized firms.[29]

It is inappropriate to generalize from a few firms to the entire industry, but it is clear that the unit of observation should be the plant (mill) rather than the firm. If the distinction between plants and firms is introduced, then even what Lazonick classified as vertically integrated firms could have spun and woven at different plants, facing the same transportation costs as the specialized firms.

[28] The Worrall's directory rarely provides information on how the total spinning and weaving capacity is divided among the mills of one firm.

[29] In 1890 the average ratio across all the vertically integrated firms was 55.9 spindles per loom; the standard deviation was equal to 42.2, the maximum was 408.9; and the mimimum was equal to 2.2. One might argue that the heterogeneity in the type of cloth being produced would lead to heterogeneity in this ratio. In particular, if you are producing coarse cloth you need far fewer spindles per loom than if you are producing fine yarn. To check this possibility, I recomputed the average number of spindles per loom only for the producers of finer goods. I found the average ratio to be equal to 58.1 and the standard deviation equal to 52.0. Thus, heterogeneity in the ratio of spindles to looms is not driven by the fineness of the cloth produced.

4.2 The Adoption of Ring Spinning over Time and Across Types of Firms

Table 4.a lists the firms that reported the use of ring-spinning in 1887, 1890 and 1894.[30] I also use data from 1885 and 1887 to show whether firms changed their vertical structure by the time they had adopted ring spinning in 1887. The firms reported in **Table 4.a** are the early adopters of rings in the Lancashire cotton industry. The table reports whether the firm was a spinner-only (S), a weaver-only (W) or vertically integrated (VI). I also report the name of the firm (abbreviated), the district where the firm was located, and the number of ring spindles that were owned by the firm in each of those five years. The firm might also report mule spindles but for sake of simplicity they are not reported in the table. If the firm reports the number of spindles but does not say how many of them are rings vs how many are mules, then the number of spindles is reported in brackets. **Table 4.b** lists the firms that reported the use of ring-spinning in 1902, and is organized in the same fashion as **Table 4.a. Table 4.c** lists the firms that reported the use of ring-spinning in 1910, but, for sake of brevity, does not report the number of ring spindles that they owned.[31]

Column 1 of **Table 5** shows the total *cumulative* number of firms that adopted rings over time. In 1887, only 9 firms reported that they had adopted ring-spinning, 3 of which were newly formed firms relative to 1885. Of the other 6 firms, we know that the firm Bury Cotton Spinning and Manufacturing Co. (located in the district of Bury) had been in the industry since 1840; Heywood Cotton Spinning and Manufacturing Co. (in Heywood) since 1860;[32] New Lady House Cotton Spinning Co. (in Rochdale) since 1877. Seven of these nine firms were still present in 1910,

[30] See the Appendix for a more detailed discussion on the collection of the data used in **Tables 4a, 4b, 4c**.

[31] This information is available from the author. It is used to construct **Figure 3.**

[32] Notwitshanding its name (manufacturing usually means that the firm also weaves its yarn), this firm was a spinner-only in all of the Worrall's directories that I used. My guess is that this firm had originally been vertically integrated and then did not change its name when it discontinued its weaving operations.

suggesting that they thrived after the adoption of ring-spinning.

25 firms had adopted rings by 1890. This was still a small number relative to the almost one thousand firms that were spinning yarn in Lancashire. 58 firms had adopted rings by 1894. By 1902, the number of firms that had adopted rings was already 109, around 10 percent of the total number of firms in the industry. 330 firms, or approximately one third of the spinning firms in Lancashire, had adopted rings by 1910. Some remarkable ones, which adopted rings more than twenty years after this technology first became available, are the vertically integrated firm Bury & H.(located in the Bury district), which had been in the industry since 1840, and the vertically integrated firm Ashton (in Hyde), which had been in the industry since 1780. These were presumably very well managed vertically integrated firms and yet they did not adopt rings as soon as they could have done.

Finally, **Tables 4.a, 4.b,** and **4.c** show that the districts of Manchester, Oldham, and Rochdale contained the largest number of firms that had adopted rings by 1902. By 1910, most of the districts had firms that had adopted rings.

We can now check whether the first of Lazonick's deductive arguments withstands the test of the new firm-level data. Lazonick claimed that British entrepreneurs should have vertically integrated in order to escape the higher transportation costs of shipping ring yarn. One of his arguments was that "ring spindles were installed disproportionately in integrated mills, 46 percent of all ring spindles being in these mills in 1913."[33] That is, Britain would have adopted rings much more quickly if more firms had been vertically integrated.

Column 2 of **Table 5** reports the number of spinners-only that had adopted rings. By 1887,

[33] Lazonick [1981], page 98.

eight out of nine firms reporting ring spindles were non-integrated. By 1890, 23 out of 25 were non-integrated. By 1902, only around 20 percent of the adopters were vertically integrated firms.

One novel and striking finding is that during the period between 1902 and 1910 vertically integrated firms started adopting ring-spinning in a systematic fashion. Of the 221 firms that adopted rings between 1902 and 1910, 50 percent of them were vertically integrated. In 1910 the vertically integrated firms controlled 40 percent of the ring spindles in Lancashire, which is a percentage very close to the 46 percent found by Lazonick for 1913. Thus, Lazonick did not get the numbers wrong in 1913. What he got wrong was the projection back in time for the earlier years when, contrary to his conclusions, the non-integrated firms were the first to adopt rings. Only after 1902, during the last period of expansion of the Lancashire cotton industry, did vertically integrated firms start to adopt ring-spinning. If integration had anything to do with failure, it would have been seen in the data since the very beginning. It did not.

The second of Lazonick's arguments was that the British continued to use new mules to replace retired mules, rather than adopting rings. To support this conjecture, Lazonick claimed that "a large proportion of the increase in ring spindles consisted of ring-frames installed in new mills or extensions of old mills, and hence did not replace retired mules."[34]

Column 3 of **Table 5** shows that until 1902 almost all of the firms that adopted rings were incumbents in the industry. Most of these firms, already in the industry, were adopting rings to replace old mules or to expand their production. After 1902, many new firms adopted rings as well. This is understandable: the first decade of the twentieth century was a period of great expansion for the Lancashire cotton industry, and it is natural that new entrants would also adopt rings.

[34] Lazonick [1981], page 96.

However, the key observation here is that the large majority of firms that adopted rings by 1910 were incumbents. The type of entrepreneurial failure imagined by Lazonick would have shown up in the data as new entrants adopting faster than the incumbents.[35] They did not. Only 24 percent of the firms that had adopted rings by 1910 were new firms.

Column 4 of **Table 5** reinforces this observation by showing that most of the new firms were spinner-only firms. This observation is particularly striking when coupled with another one, which is underscored in **Column 5** of **Table 5**: almost no firm changed its organizational form (e.g. from being a spinner-only to being a vertically integrated firm or viceversa) upon the adoption of ring spinning. Moreover, we can use the information in **Tables 4a**, **4b**, and **4c** to see that out of the seven firms that changed organizational form, only Rostron in Rochdale and Hindle in Blackburn vertically integrated their weaving and spinning upon the adoption of ring spinning. The other five vertically *de-integrated* their operations.

Finally, we can use **Tables 4a**, **4b**, and **4c** to look at the number of ring spindles installed in order to learn about the distribution of the *number* of ring spindles installed. The idea here is the following: if it had been the case that ring spindles were installed in new mills or in extensions of old mills, then we would expect firms to install a large number of spindles. If, instead, rings were being slowly adopted to replace retired mules, then we would observe much more variation in the number of spindles. **Figure 3** shows the distribution of the *number* of ring spindles installed in 1910.[36] It is clear that there was a very large number of small installations (one quarter of them

[35] His claim that ring-frames were installed in extensions of old mills would be extremely hard to test because one would have to collect information on the size of each firm's mills. It is not even clear how Lazonick can make that statement in the first place, since he did not employ the firm-level information in the Worrall's Directories in conjunction with some other data source with information on the size of the mills, such as the Ordnenance Surveys.

[36] To draw this graph I only use firms for which we definitively know the number of ring spindles installed between 1902 and 1910. Fewer than 10 percent (20 out of 221) of the firms that reported that they had installed rings in 1910

was for fewer than 8200 spindles), which is hard to reconcile with the idea that they were adopted by new firms, and it instead suggests that firms were slowly replacing the old mules with new ring spindles.

4.3 The Adoption of Rings for Weft Yarn: Integrated versus Non-integrated Firms

The last of Lazonick's arguments is that the costs of shipping ring weft yarn were enormously larger for a non-integrated firm than for an integrated firm. This made vertical integration even more economically efficient than specialization. To support this hypothesis, Lazonick claimed that "prior to World War I ring frames were rarely used for spinning weft yarns in non-integrated mills."[37]

Earlier writers have assumed that vertically integrated firms produced both twist and weft yarn. This was not necessarily true, as shown in **Table 6**. The top panel of **Table 6** shows the distribution of firms in the production of weft and yarn. We observe that both in 1890 and 1910, approximately 70 percent of the vertically integrated firms were spinning both weft and twist yarn. The remaining vertically integrated firms had to buy either weft or twist to weave their cloth. These firms were buying weft yarn on the market. For example, the firms Thornber in Burnley, Nuttal in Farnsworth, Barker in Todmorden, and others had adopted rings to produce twist yarn. They were buying the weft yarn for their weaving production (or they were selling their surplus of twist yarn on the market). As already noted, not many of the vertically integrated firms were buying weft yarn (or selling twist yarn), but it is notable that few of these ones had actually adopted rings. This surprising result is even stronger for spinner-only firms. Only around 60 percent of

did not provide the exact number of ring spindles that they had installed.

[37] Lazonick [1981], page 98.

them were spinning both twist and yarn. What is particularly cogent for the analysis here is that the percentages did not change between 1890 and 1910. This necessarily implies that vertically integrated firms did not feel that is was necessary to produce both weft and twist in order to avoid the presumed cost of shipping ring weft yarn.

The middle panel reports the results using spindleage capacity rather than the number of firms. Here, the results are less dramatic. In 1890 and 1910, approximately 90 percent of the spindling capacity of vertically integrated firms was in firms that were spinning both weft and twist yarn. The results in the top and middle panel imply that large integrated firms generally produced both types of yarn. Some small vertically integrated firms produced only one of the two.

The bottom panel reports the distribution of the spindling capacity by the fineness of the cloth woven and by whether twist and weft spinning was done together. We observe that the percentages in this bottom panel basically follow the ones in the middle panel. For example, in 1890, 85.4 percent of the total spindleage capacity of the vertically integrated firms was used in the production of coarse goods (count $0-40$) by firms that were spinning both twist and weft. 70 percent of the total spindleage capacity of the spinner-only firms was used in the production of coarse goods (count $0-40$) by firms that were spinning both twist and weft. These percentages were largely unchanged in 1910.

There are two key insights from **Table 6**. First, vertically integrated firms that were only spinning twist or weft yarn were still in existence in 1910. If the costs of shipping ring weft yarn were, in practice, as large as calculated by Lazonick and Leunig, then this sub-type of vertically integrated firms should have declined over time, but it did not. Second, the shares of spindleage

capacity and the number of firms that were vertically integrated and spinner-only firms did not change over time. If vertical integration was really the more efficient way to organize cotton production, we would have observed a decline in the number and spindleage capacity of spinner-only firms, but that did not happen.

4.4 Producing Finer Goods

To conclude this section on a positive note, I now use the new firm-level data to provide additional evidence in favor of Leunig's explanation for Lancashire's continuing preference for the mule: the strong demand for fine yarn and the sizeable yarn-export trade.

Table 7 shows that distribution of the spindleage capacity by cloth fineness and by the organization of the firms. In 1890, 75.6 percent of the spindleage capacity of the vertically integrated firms was for the production of coarse goods (counts between 0 and 40).[38] Among the spinner-only firms, 53.4 percent of the spindleage capacity was for the production of coarse goods.

The striking piece of evidence is that between 1890 and 1910 there was a dramatic decline in the percentage of spindleage dedicated to the production of coarse goods. In 1910, only 36.8 percent of the spindleage capacity of the spinner-only firms was used to produce coarse goods, down from 53.4 percent. Similarly, 64.9 percent of the spindleage capacity of the vertically integrated firms was used to produce coarse goods, down from 75.6 percent.

Table 7 provides evidence of a highly specialized industry. Spinner-only firms specialized in the production of fine goods, while vertically integrated firms specialized in the production of coarse goods. Because the spindleage capacity of spinner-only firms was twice as large as that of vertically

[38] This number is remarkably close to the one reported by Leunig [2001].

integrated firms, and because ring-spinning was not the most efficient way to produce fine goods, this largely explains why rings were adopted so slowly in Britain at the end of the 18th century.

5 Why Did Vertically Integrated Adopted Rings So Late?

A striking and novel finding is that vertically integrated firms had essentially not adopted any ring-spinning until 1902, and then suddenly they started adopting the rings at a faster pace than spinning-only firms. This is clear when we look at **Table 5**. Until 1902, the large majority (87 out of 109, approximately 80 percent) of the firms adopting rings were spinner-only firms. By 1910, the percentage of firms that were spinner-only was down to 59 percent (197 out of 330). Why did vertically integrated firms suddenly start adopting rings?

One very compelling explanation is related to the timing of the introduction of the Northrop automatic loom in Britain. As Sandberg [1974] discusses, the Northrop loom was first introduced in 1902, and in 1904 the British Northrop Loom Company was established. The Northrop loom was not suited for fine goods, which, as we saw, were mainly produced by spinner-only firms. However, the Northrop loom was particularly efficient at the production of coarse goods, which was the segment of the market mostly covered by vertically integrated firms. Thus, vertically integrated firms should have been adopting the new automatic loom, but, as Sandberg reports, they did it at a dramatically slow rate. Remarkably, in Worrall's Directory of 1910 there is one *new* vertically integrated firm, Eccles Spinning & Manufacturing Co, formed in 1905 and located in Patricroft, Manchester, which simultaneously adopted rings and Northrop looms.

The crucial insight here is that automatic looms required the greater strength of ring-spun as opposed to mule-spun yarn (Sandberg [1974]). As Sandberg explains, the complementarity between

ring-spinning and automatic weaving meant that plans to install automatic looms depended on the availability of ring-spinning.

Vertically integrated firms, which mainly produced coarse goods and whose survival was clearly at stake against foreign competitors, must have realized that they had to adopt rings in order to exploit the advantages of the automatic looms. This intepretation explains the sudden and dramatic increase in the rate of adoption of rings after 1902.[39]

6 Conclusion

This paper uses firm-level data to show that entrepreneurial failure does not explain the decline of the Lancashire cotton industry before World War I, at least as long as the test for entrepreneurial failure is based on differences in the adoption of rings between vertically integrated and non-integrated firms.

This paper shows that the Lancashire cotton industry was highly specialized, with vertically integrated firms producing primarily coarse goods and spinner-only firms producing primarily yarn for fine goods. This, together with the fact that the spindleage capacity of spinning-only firms was twice as large as that of vertically integrated firms and the strong demand for fine yarn and the sizeable yarn-export trade, explains Lancashire's continuing preference for the mule.

This paper also uncovers a new important finding: vertically integrated firms had essentially not adopted any ring-spinning till 1902, and then suddenly they started adopting the rings at a faster pace than only-spinning firms. Though more research is warranted to explain this finding,

[39] To support this explanation, one could check the cotton company reports or trade journals and verify whether the sudden change in the behavior of vertically integrated firms was driven by the awareness that only with both automatic looms and ring-spinning could the producers of coarse goods have survived the international competition. This is left to future research.

here I propose an explanation based on the complementarity between ring-spinning and automatic weaving. Vertically integrated firms had to adopt ring-spinning before adopting the automatic looms. This intuitive explanation elucidates why rings were adopted so late by vertically integrated firms, and why automatic looms were adopted so slowly by British entrepreneurs.

7 Appendix

The data are from the Worrall's Cotton Spinners' and Manufacturers' Directories of 1885, 1886-7, 1890, 1893-4, 1902 and 1910. These data contain information on the names of the firms, locations, and types of spindles used by cotton firms in Lancashire. They also contain information on the number of spindles (and looms) used by each firm, the fineness of the product manufactured, and whether the firm spun twist, weft, or both. Farnie [1979] discusses the reliability of the Worrall's Directories.

This Appendix discusses three data coding choices.

Firms and Mills. In a few cases mills changed ownership across the years. In those cases, with one exception (Meanock Ellis in Mossley, discussed below) I used the mill as the relevant unit of observation. For example, if the firm Tay in Oldham acquired a mill that was already in existence and placed rings in that pre-existing mill, then I coded the firm Tay as an incumbent and not as a new entrant adopting rings. A different coding choice would have only a marginal effect on the results of this paper, because few mills changed ownership and adopted rings at the same time. In 1902 there were 7 firms out of 51, or 13 percent of the firms, which fit this description. There were only a handful in 1910, by which time more than 200 firms had adopted rings.

Potential for Misreporting. Firms are listed in **Table 4a, 4b,** and **4c** as having adopted rings when they first reported rings in the Worrall's Directories. This is not an obvious data coding decision because in some cases there is reason to believe that firms might have adopted rings before the listed year. For example, the firm Palm Mill in Oldham reported $40,000$ ring spindles in 1887 and $40,000$ (type not specified) spindles in 1885. One might be tempted to infer that the firm

Palm Mill had adopted rings already in 1885. In this paper I have decided not to make this type of assumptions and instead I have coded the data exactly as it is in the Worrall's directories. To get a sense of the possible misreprentation problem, I identified 47 firms out of the 330 (i.e. 13 percent of the sample) that had adopted rings by 1910 and for which one could possibly argue that the firms had adopted rings earlier than what is reported in the Worrall's directories.

These firms are Walker in Hyde, Victoria in Manchester, Lees H. in Oldham, Arkwright in Rochdale, Healey in Rochdale, Glodwick in Oldham, Lees in Oldham, Mutual in Heywood, Roach in Heywood, Irk Mill in Middleton, Wood T. B. in Middleton, Stott James in Oldham, Park Lane in Preston, Halliday in Wigan, Dyson Eli in Farnsworth, Hodgkinsons in Heywood, Isherwood in Heywood, Railway in Heywood, Roe Acre in Heywood, Storey in Lancaster, Broadbent in Manchester, Richardson in Manchester, Millbrook in Stalybridge, Staley in Stalybridge, Shepherd R. in Waterfoot, Witham in Burnley, Bury & Elt. in Bury, Holdsworth in Manchester, Clegg in Oldham, Tattersall in Rochdale, Heginbottom in Ashton, Thompson Richard in Blackburn, Trafalgar in Burnley, Bury Coop in Bury, Wood in Glossop, Sefton Mill in Heywood, Burton in Leigh, Armitage in Manchester, Rylands in Manchester, Eccles T. in Preston, Broadley in Rochdale, Harrison in Stalybridge, Pearson in Stockport, Barker W. in Todmorden, Fielden in Todmorden, and Eckersleys in Wigan.

The only firms for which I use an imputation methodology are Haugh in Rochdale and Meanock Ellis in Mossley, which I list as new entrants in 1887, even though they were already in the market in 1885. The point here is that both Haugh in Rochdale and Meanock Ellis in Mossley entered into the market when they installed rings, so for the purposes of my analysis (**Table 4.a**) they should

really be considered as new entrants. Notice that Meanock Ellis used a pre-existing mill, but I still consider it as a new entrant. It is the only case in the dataset for which I make this choice.

Of these 47 firms, 26 (i.e. 54 percent) were spinner-only. Because the fraction of firms *potentially* misreporting is small (approximately 10 percent), and because both spinner-only and vertically integrated firms are included in this group, there is no reason to think that misreporting should bias the results of the analysis against vertically integrated firms.

Inconsistencies in the Worrall's Directories. For 1902 and 1910 the Worrall's Directories provide information on the count of the yarn spun by the firms and on the type of spindle used – whether ring, water, or mule – in two locations. First, as part of the complete firm listing, together with the information on the number of spindles and the names of the mills owned. Second, at the end of the Directories, where there is an alphabetical list of the firms in Lancashire. These two sources of information are not always consistent with each other. Here, I take the superset of the two sets of information. In other words, if a firm is reported to having adopted rings in either one of the locations then I code the firm as having adopted rings.

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Table 1: Fineness				
1	12	2	23	3
Twist 0-20	Twist in 10s	Twist 20-40	Twist 20-40	Twist >40
Weft 0-30	Weft in 20s	Weft 20-40	Weft in 40s	Weft >50
Alhambra	Chasmeres	Calico	Dhooties	Cambrics
Beaverteens	Colored Goods	Check, Nainsook	Jacconettes	Check, Dimity
Cords	Cotton Italians	Covers	Lenos	Check, Lawn
Crapes	Domestics	Dobbies	Mulls	Dimities
Denim	Florentines	Flanellettes	Sateen	Fancy White Goods
Drill	Grandrills	Fustians	Turkey Reds	Gingham, Fine
Flannel	Mottles	Gingham	Velvet	Silk Velvets
Honeycomb towels	Nankeens	Gingham, Chambray	Velveteen	
Huckaback	Regattas	Handkerchief		
Imperials	Satin Tops	Harvards & Oxfords		
Lambskins	Stripe	India & China Shirtings		
Mexicans	T Cloths	Jeannettes		
Osnaburg	Ticks	Long Cloth		
Sheeting	Twills	Madapollams		
Sheeting, Heavy	Worsted Cords	Muslins		
Swansdowns	Zephyrs	Pique		
Towels		Printers		
Turkish towels		Prints		
Wigan		Quilts, Plain and Fancy		
		Sheeting, Bleached		
		Sheeting, Wide		
		Shirting		
		Split		
		Tanjibs		
		Toilet		
		Zephyrs		

Source: Worrall's Directories of Cotton Spinners and Manufacturers, 1885, 1886-7, 1890, 1893-4, 1902, 1910.
Notes: This classification is constructed using the products that the firms claimed to be manufacturing. This approach ensures that the classification is internally consistent with the data on spindles and mules reported in the directories.

Table 2: Spinning Capacity in Lancashire

Total Number of Spindles(%)	*Spinners Only*	*Vertically Integrated Firms*
1890	64.4	35.6
1902	71.0	29.0
1910	78.8	21.2
	Number of Firms by Type	
1890 (%)	557 (62.2)	350 (37.8)
1902 (%)	556 (64.9)	300 (35.0)
1910 (%)	683 (70.7)	283 (29.3)

Data: Worrall's Directory of Cotton Spinners' and Manufacturers, 1890, 1902, 1910.
The reported numbers of observations does not include firms for which we have missing information.

Table 3: The Best Practice Choice of Technique		
	Twist	Weft
Not including Transportation Costs (Vertically Integrated Firm)	0-40 (R) 40+ (M)	0-40 (R) 40+ (M)
Including Transportation Costs (Non-Integrated Firm)	0-40 (R) 40+ (M)	(M)

Sources: Leunig *Myth*, Table 24, p. 66, is used to compute the labor and raw cotton costs. Lazonick "Factor Spinning," Table II, p. 101, is used to compute the transportation costs. For example, Leunig reports that the net savings from the adoption of ring spinning were equal to 0.11 cents per pound: ring spinning would have saved 0.41 cents in labor costs but would have increased by 0.30 the raw cotton costs. Lazonick computes the additional transportation costs for weft to be equal to 0.54 cents per pound.

Note: The capital letter in parenthesis denotes the best practice. For example, rings were the best technique for counts 0/40 in vertically integrated firms.

Table 4a - Adoption Patterns in 1887, 1890 and 1894

Name of the Firm	District	Type in 1885	Type in 1887	Spindles in 1887
Bury Cott	Bury	VI	VI	[50000]
Heywood	Heywood	S	S	19296
Meanock	Mossley	0	S	[16500]
Palm Mill	Oldham	S	S	40000
Castleton	Rochdale	S	S	26000
Haugh	Rochdale	0	S	25300
New Lady	Rochdale	S	S	16016
Newhey	Rochdale	0	S	35200
Lees	Warrington	S	S	[20000]
		Type in 1887	**1890**	**Spindles in 1890**
Tottington	Bury	VI	S	11000
Taylor	Denton	S	S	1800
Shepley	Glossop	VI	VI	5420
Smithson	Golborne	S	S	2400
Walker	Hyde	S	S	[40900]
Pendleton	Manchester	W	S	12000
Victoria	Manchester	S	S	[44500]
Cambridge	Oldham	S	S	4736
Clough	Oldham	S	S	1184
Greenacres	Oldham	S	S	[114034]
Lees H.	Oldham	S	S	8000
Textile Mill	Oldham	S	S	[95520]
Allen Bros.	Radcliffe	VI	S	10000
Arkwright	Rochdale	S	S	23000
Healey	Rochdale	S	S	9800
Walker J&G	Rochdale	S	S	36000
		Type in 1890	**Type in 1894**	**Spindles in 1894**
Bayley	Bolton	S	S	[100360]
Holdsworth	Bolton	S	S	[47000]
Wolfenden	Bolton	S	S	[57000]
Witham	Burnley	VI	VI	[48504]
Alcock	Bury	VI	VI	2316
Bury & Elt.	Bury	VI	VI	[50000]
Vulcan	Bury	0	VI	40000
Alpha Mill	Denton	S	S	[57000]
Burns	Heywood	0	S	43000
Kay Richard	Heywood	S	S	25000
Taylor James	Heywood	S	S	7000
Hibbert	Hyde	VI	VI	1480
Garlick & Dyson	Manchester	S	S	[30000]
Hanover Mill	Manchester	S	S	17000
Holdsworth	Manchester	VI	VI	26000
Johnson	Manchester	S	S	10000
Middleton & T.	Middleton	S	S	9024
Busk	Oldham	0	S	6400
Clegg	Oldham	VI	VI	75326
Glodwick	Oldham	S	S	79968
Holden	Oldham	S	S	[8180]
Lees	Oldham	S	S	[75000]
Seville S&E	Oldham	S	S	1648
Stock Lane	Oldham	S	S	10000
Park Lane	Preston	S	S	[50000]
Rostron	Radcliffe	W	VI	16000
Balderstone	Rochdale	S	S	17000
Eagle	Rochdale	0	S	[89000]
Tattersall	Rochdale	VI	VI	[15000]
Yates	Rochdale	VI	VI	8000
Jackson & S.	Stalybridge	0	VI	4000
Uppermill	Uppermill	S	S	10280
May Mill	Wigan	0	S	21600

Source: Worrall's Directory of Cotton Spinners' and Manufacturers 1885, 1886-7, 1890, 1893-4.

Notes:

(1) If the firm was a spinner-only, then it is coded with S; weaver-only are coded with W; vertically integrated firms are coded with VI.

(2) If the firm is a new entrant, then a 0 is reported for the preceding period.

(3) If the firm reports the number of spindles, but does not say how many of them are rings, then the number of spindles is reported in brackets.

Table 4b - Adoption Patterns in 1902

Name of the Firm	District	Type in 1894	Type in 1902	Spindles in 1902
Imperial Mill	Blackburn	0	S	67000
Brookfield	Bolton	S	S	[25000]
Lord	Bolton	S	S	[85640]
Moorlands	Bolton	0	S	[32340]
Park Mill	Bolton	S	S	[102882]
Thornber	Burnley	VI	VI	43000
Higher Mill	Bury	S	S	6400
Century	Farnsworth	0	S	51000
Nuttall	Farnsworth	VI	VI	[87500]
Record	Golborne	0	S	31190
Brook	Heywood	S	S	[26000]
Healey	Heywood	0	S	8500
Mutual	Heywood	S	S	[160000]
Roach	Heywood	S	S	[43000]
Christy W. M.	Manchester	VI	VI	[21000]
Pendlebury	Manchester	S	S	31200
Taylor	Manchester	S	S	2276
Irk Mill	Middleton	S	S	[40000]
Tonge Vale	Middleton	S	S	6808
Wood T. B.	Middleton	S	S	20000
Egmont	Mossley	0	S	7000
Booth	Oldham	S	S	1300
County End	Oldham	S	S	2304
Dawn Mill	Oldham	0	S	8000
King Spinn.	Oldham	0	S	17880
Lamb Mills	Oldham	0	S	10000
Nile	Oldham	0	S	64000
Oldham	Oldham	S	S	[88512]
Oxford Mill	Oldham	S	S	[40000]
Pearl Mill	Oldham	S	S	6228
Stott James	Oldham	S	S	25000
Tay	Oldham	S	S	[28200]
Taylor James	Oldham	S	S	4432
Taylor Thomas	Oldham	S	S	3840
Catterall P.	Preston	S	S	[39536]
Park Lane	Preston	S	S	[50000]
Era Mill Co.	Rochdale	0	S	59600
Holt & O.	Rochdale	S	S	14000
Union Ring	Rochdale	W	S	40000
Cheetam	Stalybridge	VI	VI	16000
Leech	Stalybridge	VI	VI	4800
Nuttal	Stalybridge	S	S	20000
Stalybridge	Stalybridge	S	S	1920
Brunswick	Stockport	S	S	10000
Lowe	Stockport	VI	VI	9000
Moorhouse	Stockport	S	S	30700
Stockport	Stockport	0	S	64456
Barker	Todmorden	VI	VI	7500
Greenwood	Todmorden	S	S	7020
Eccles	Uppermill	0	S	[35000]
Halliday	Wigan	S	S	10000

Source: Worrall's Directory of Cotton Spinners' and Manufacturers 1893-4, 1902.

Notes:

(1) If the firm was a spinner-only, then it is coded with S; weaver-only are coded with W; vertically integrated firms are coded with VI.

(2) If the firm is a new entrant, then a 0 is reported for the preceding period.

(3) If the firm reports the number of spindles, but does not say how many of them are rings, then the number of spindles is reported in *brackets* .

Table 4c - Adoption Patterns in 1910

Name of Firm	District	Type in 1910 (Type in 1902)	Name of Firm	District	Type in 1910 (Type in 1902)	Name of Firm	District	Type in 1910 (Type in 1902)	Name of Firm	District	Type in 1910 (Type in 1902)
Canal Mills	Accrington	VI	Broad Mills	Glossop	VI	United	Oldham	S	Goyt	Stockport	S*
Roe Greave	Accrington	VI	Gartside	Glossop	VI	Wood J.	Oldham	S	Hollins	Stockport	VI
Stanhill	Accrington	S*	Platt	Glossop	VI	Ingham W.	Padiham	VI	Hollins, Marple	Stockport	VI
Gartside	Ashton	VI	Rhodes	Glossop	VI	Calvert I	Preston	VI	Howard	Stockport	S
Heginbottom	Ashton	VI	Sumner	Glossop	VI	Calvert II	Preston	VI	Kershaw	Stockport	VI
Hurst Mills	Ashton	VI	Wood	Glossop	VI	Copland	Preston	S	Kingston	Stockport	S
Kershaw James	Ashton	S	Thompson	Great Harwood	VI	Dewhurst	Preston	VI	Mellor	Stockport	S
Mason Thomas	Ashton	S	Hazel Mill	Haslingden	S	Eccles Brot.	Preston	VI	Palmer	Stockport	S
Mellor Thomas	Ashton	VI	Albert	Heywood	S	Eccles T.	Preston	VI	Pearson	Stockport	VI
Reyner	Ashton	VI	Hodgkinsons	Heywood	S	Eccles W.	Preston	VI	Shepley	Stockport	VI
Whittakers	Ashton	VI	Hopwood	Heywood	S	Hartford	Preston	VI	Stockport 2	Stockport	S*
Coddington	Blackburn	VI	Isherwood	Heywood	S	Hawkins	Preston	VI	Stockport 3	Stockport	S*
Codling & H.	Blackburn	VI	Park Street	Heywood	S	Leigh	Preston	VI	Vernon	Stockport	S*
Daisyfield Ring	Blackburn	S*	Railway	Heywood	S	Orr	Preston	VI	Warks	Stockport	VI
Dugdale Thomas	Blackburn	VI	Roe Acre	Heywood	S	Oxhey	Preston	VI	Barker W.	Todmorden	VI
Fish John	Blackburn	VI	Sefton Mill	Heywood	VI	Paley	Preston	VI*	Dugdale	Todmorden	VI
Hindle E. & G.	Blackburn	VI(W)	Unity	Heywood	S*	Preston	Preston	VI	Fielden	Todmorden	VI
Hollin Bank Ring	Blackburn	S*	Ashton	Hyde	VI	Preston	Tulketh	S*	Sutcliffe	Todmorden	S*
Lewis Brothers	Blackburn	VI	Slack Mills	Hyde	VI	Black Lane	Radcliffe	S*	Vic Mill	Uppermill	S*
Longwoth	Blackburn	VI	Storey	Lancaster	S	Radcliffe	Radcliffe	S	Pickup	Waterfoot	VI
Mellor	Blackburn	S*	Jones	Leigh	VI	Wilton	Radcliffe	S*	Shepherd	Waterfoot	S
Rishton	Blackburn	VI	Burton	Leigh	VI	Cuba	Ramsbottom	S*	Shepherd R.	Waterfoot	S
Thompson	Blackburn	VI	Clegg E.	Littleborough	VI	Ashworth	Rawtenstall	VI	Whitewell	Waterfoot	VI
Whiteley	Blackburn	VI	Schofield J.K.	Littleborough	VI	Haworth	Rawtenstall	VI	White	Waterfoot	VI
Ainsworth	Bolton	S	Sladen	Littleborough	VI	Newchurch	Rawtenstall	VI	Brown	Wigan	VI
Brown	Bolton	S	Acme	Manchester	S*	Rawtenstall	Rawtenstall	VI	Crescent	Wigan	S*
Crosses	Bolton	S	Armitage	Manchester	VI	Globe	Rawtenstall	VI	Eckersleys	Wigan	VI
Greenhalgh	Bolton	S	Armitage 2	Manchester	VI	Blackpits	Rochdale	VI	Empress	Wigan	S*
Hamer	Bolton	S	Ashworth	Manchester	S	Bridgefield	Rochdale	S*	Woods	Wigan	S(VI)
Hesketh	Bolton	S	Barlein	Manchester	S	Brierley	Rochdale	VI			
Maco	Bolton	S*	Bannerman	Manchester	S	Bright	Rochdale	VI			
Marsden	Bolton	S	Broadbent 1	Manchester	S	Broadley	Rochdale	VI			
North End	Bolton	S	Broadbent 2	Manchester	S	Coral Mill	Rochdale	S*			
Tootal	Bolton	VI	Eccles	Manchester	VI*	Crest Ring	Rochdale	S*			
Folds	Burnley	VI	Ermen & R.	Manchester	S	Dale	Rochdale	S*			
Hill Top	Burnley	VI	Gladstone	Manchester	S	Dicken	Rochdale	S*			
Oxford	Burnley	VI	Langworthy	Manchester	VI	Eastwood	Rochdale	S*			
Trafalgar	Burnley	VI	Regent Mill	Manchester	S*	Facit	Rochdale	S*			
Bury Coop	Bury	VI	Richardson	Manchester	S	Hamer	Rochdale	S			
Bury & H.	Bury	VI	Rylands	Manchester	VI	Hargreaves	Rochdale	VI			
Hutchinson	Bury	VI	Togo Spin.	Manchester	S*	Higham	Rochdale	VI			
Kenyon	Bury	VI*	Cromer	Middleton	S*	Hoyle	Rochdale	VI			
Kenyon	Bury	VI	Soudan	Middleton	S*	Millgate	Rochdale	VI			
Mellor	Bury	VI	Clark & W.	Mossley	S*	Orr J&S	Rochdale	VI			
New Victoria	Bury	VI	Hopkins	Mossley	S*	Parker & H.	Rochdale	S			
Openshaw	Bury	VI	Mossley	Mossley	S*	Rochdale	Rochdale	VI			
Openshaw W.	Bury	VI	Belgrave	Oldham	S*	Shawforth	Rochdale	VI			
Pilot	Bury	S*	Briar Mill	Oldham	S*	Sparth	Rochdale	S			
Schofield	Bury	VI	Butterworth	Oldham	VI	Stuttard	Rochdale	VI			
Walker & L.	Bury	S	Clegg Broth.	Oldham	S	Townhead	Rochdale	S			
Birtwistle	Chorley	VI	Copster Mill	Oldham	S*	Valley	Rochdale	S*			
Coppull	Chorley	S*	Fitton	Oldham	VI	Victoria	Rochdale	S			
Cowling	Chorley	S*	Fox Mills	Oldham	S*	Wellfield	Rochdale	S*			
Nixon & K.	Chorley	VI	Iris Mill	Oldham	S*	Whitaker	Rochdale	S			
Talbot	Chorley	VI*	Lees Union	Oldham	S	Whitworth	Rochdale	VI			
Garnett	Clitheroe	VI	Lily Mill	Oldham	S*	Byrom	Stalybridge	S			
Mercer	Clitheroe	VI	Majestic	Oldham	S*	Harrison	Stalybridge	VI			
Primrose	Clitheroe	S*	Napier	Oldham	S*	Millbrook	Stalybridge	S			
Darwen	Darwen	VI	Orme	Oldham	S*	Premier	Stalybridge	VI*			
Eccles A.T.	Darwen	VI	Raven	Oldham	S*	Ray Mills	Stalybridge	S*			
Gibraltar	Denton	VI	Richardson	Oldham	S	Staley	Stalybridge	S			
Dukinfield	Dukinfield	S	Roy Mill	Oldham	S*	Storrs	Stalybridge	S*			
Barnes	Farnsworth	VI	Royton	Oldham	S*	Victor	Stalybridge	S*			
Dyson Eli	Farnsworth	S	Shaw Spinn.	Oldham	S	Wilkinson	Stalybridge	S			

Source: Worrall's Directory of Cotton Spinners' and Manufacturers 1902, 1910.

Notes:

(1) If the firm was a spinner-only, then it is coded with S; weaver-only are coded with W; vertically integrated firms are coded with VI.

(2) If the firm is a new entrant, then a * is reported in addition to the type of firm.

Table 5: Ring Adoption in Lancashire, 1887-1910

Year	*(1) Total Number of Firms*	*(2) Number of Only-Spinners at time of adoption*	*(3) New Firms*	*(4) New Firms Only-Spinners*	*(5) Incumbent Firms Changing Organizational Form*
1887	9	8	3	3	0
1890	25	23	3	3	3
1894	58	42	9	8	4
1902	109	87	21	20	5
1910	330	197	80	74	7

Source: Worrall's Directories of Cotton Spinners and Manufacturers, 1885, 1886-7, 1890, 1893-4, 1902, 1910.
Notes: The numbers reported in *all* the Columns of the Table are *cumulative*. For example 25 firms had adopted rings *by* 1890.

Table 6: Twist and Weft Yarn in Lancashire, 1890

	Spinners Only	*Vertically Integrated Firms*	*Total*
	Percentage of firms		
Only Twist in 1890 (%)	27.7	8.3	20.6
Only Weft in 1890 (%)	14.8	20.2	16.7
Twist and Weft in 1890 (%)	57.5	71.6	62.7
Only Twist in 1910 (%)	225	9.0	18.5
Only Weft in 1910 (%)	12.1	19.9	67.1
Twist and Weft in 1910 (%)	65.4	71.1	14.3
	Percentage of spindleage capacity		
Only Twist in 1890 (%)	22.3	6.7	17.2
Only Weft in 1890 (%)	8.4	8.9	8.6
Twist and Weft in 1890 (%)	69.3	88.4	74.2
Only Twist in 1910 (%)	14.5	5.5	12.8
Only Weft in 1910 (%)	8.0	6.0	7.6
Twist and Weft in 1910 (%)	77.5	88.5	79.6
	Percentage of spindleage capacity for counts 0-40		
Only Twist in 1890 (%)	22.8	8.4	16.9
Only Weft in 1890 (%)	6.6	6.2	6.5
Twist and Weft in 1890 (%)	70.5	85.4	76.6
Only Twist in 1910 (%)	21.9	6.7	17.2
Only Weft in 1910 (%)	6.8	5.9	6.5
Twist and Weft in 1910 (%)	71.3	87.4	76.3

Data: Worrall's Directory of Cotton Spinners' and Manufacturers, 1890, 1910.

Table 7: Spinning Capacity and Fineness in Lancashire

	Spinners Only	*Vertically Integrated Firms*	*Total*
Count 0-40 in 1890 (%)	53.4	75.6	61.1
Count above 40 in 1890 (%)	46.6	24.4	38.9
Count 0-40 in1902 (%)	50.7	67.8	55.6
Count above 40 in 1902 (%)	49.3	32.2	44.3
Count 0-40 in 1910 (%)	36.8	64.9	41.5
Count above 40 in 1910 (%)	62.9	35.1	58.4
	Number of Firms by Type		
N 1890 (%)	557 (62.2)	350 (37.8)	907
N 1902 (%)	556 (64.9)	300 (35.0)	856
N 1910 (%)	683 (70.7)	283 (29.3)	966

Data: Worrall's Directory of Cotton Spinners' and Manufacturers, 1890, 1902, 1910.

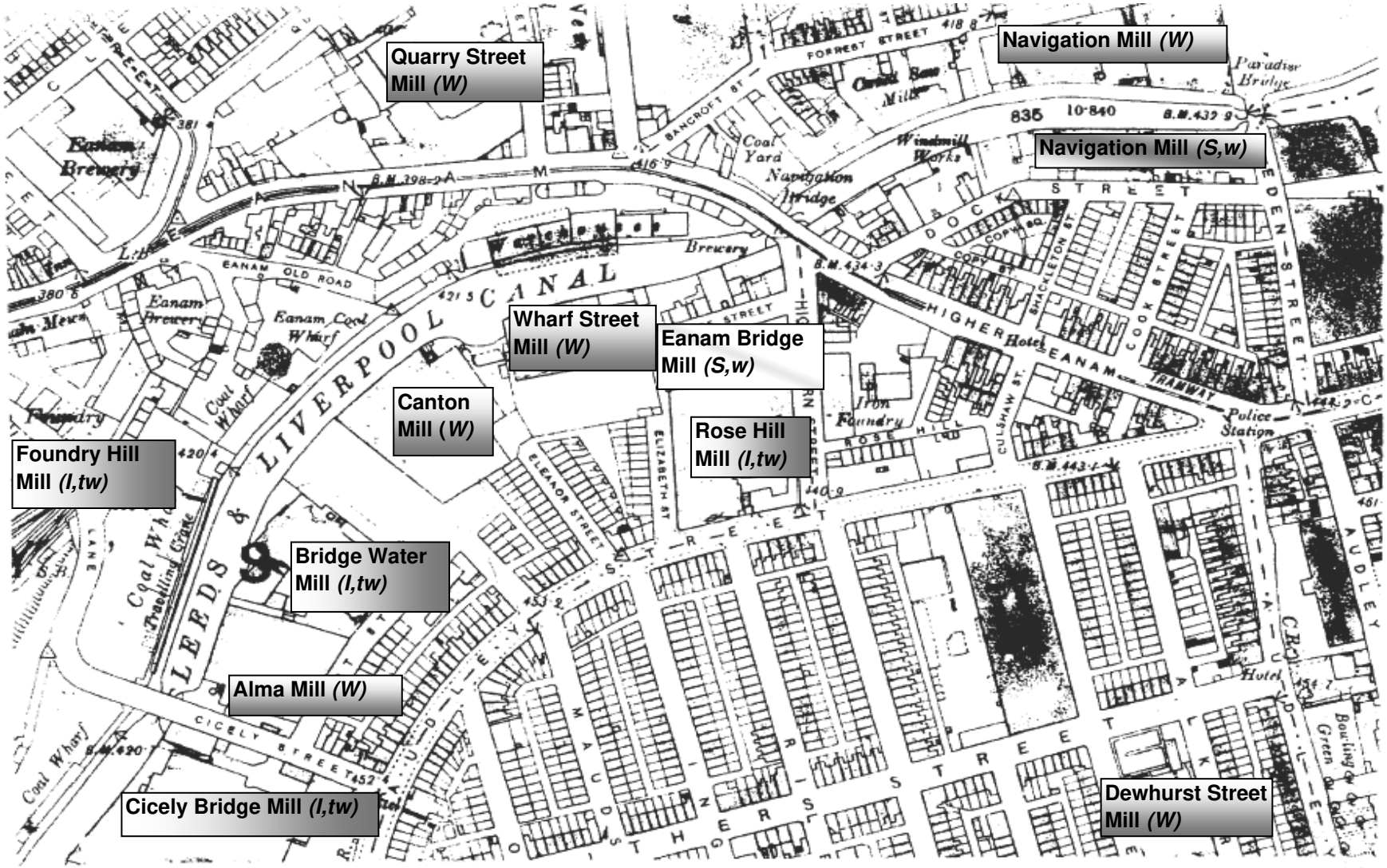


Figure 1: Location of Cotton Mills in Blackburn, 1890-1893.

Source: Ordnance Survey Map of Blackburn, 1891-92, Great Britain.

Legend: W= Weaver; S=Spinner; I=Integrated firm. w=producing only weft yarn; t=producing only twist year; tw=producing both weft and twist yarn.

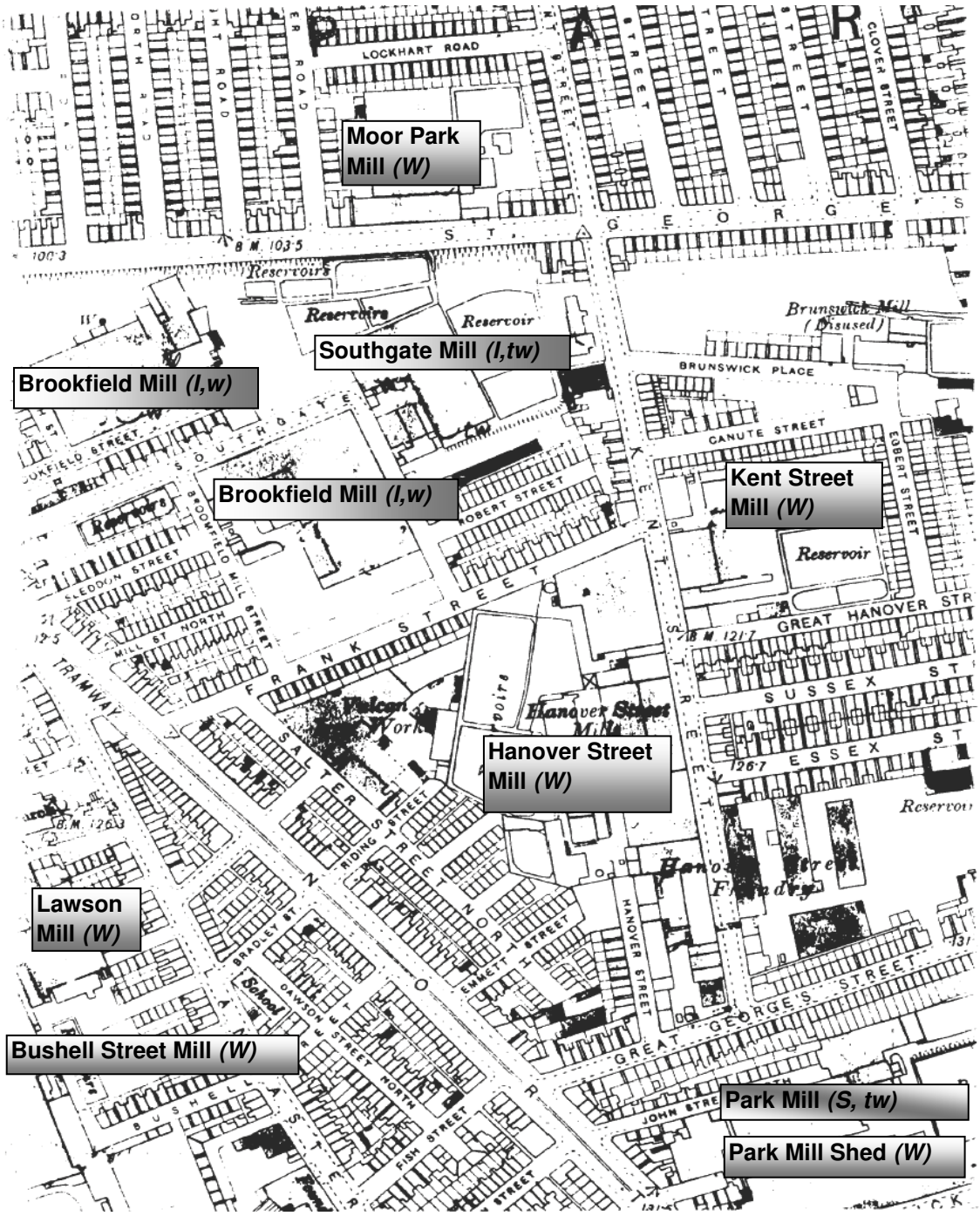
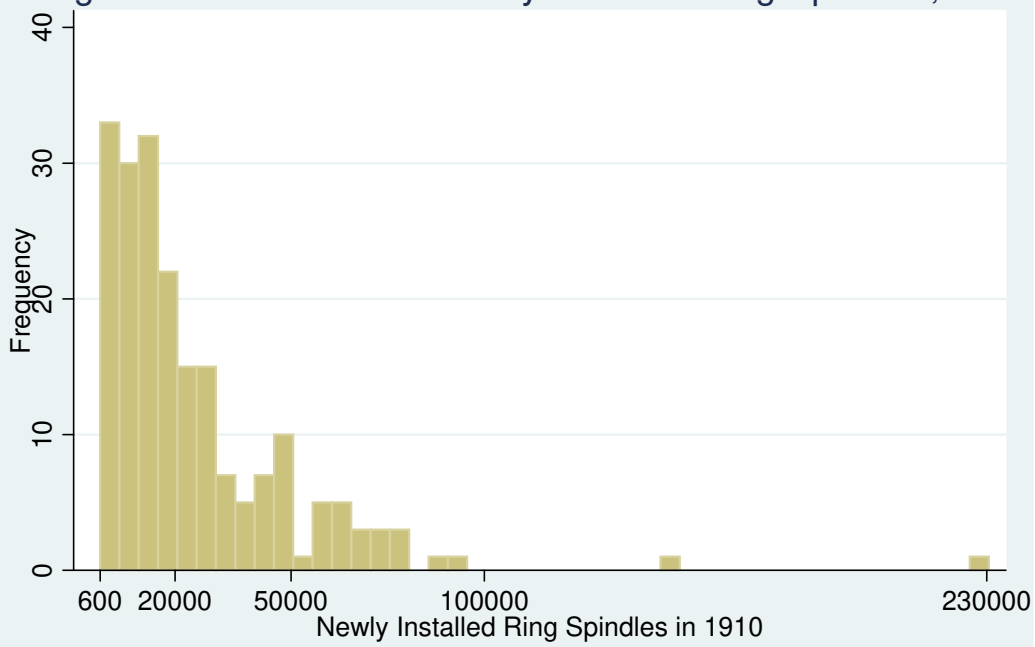


Figure 2: Location of Cotton Mills in Preston, 1890-1893.
Source: Ordnance Survey Map of Preston, 1891-92, Great Britain.
Legend: W= Weaver; S=Spinner; I=Integrated firm. w=producing only weft yarn;
t=producing only twist year; tw=producing both weft and twist yarn.

Figure 3: Distribution of Newly Installed Ring Spindles, 1910



Source: Worrall's Directory of Cotton Spinners' and Manufacturers, 1902, 1910.