Tim Leunig

A British industrial success : productivity in the Lancashire and New England cotton spinning industries a century ago

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A British Industrial Success:
Productivity in the Lancashire and New England
Cotton Spinning Industries a Century Ago.[1]

Dr Tim Leunig
Lecturer in Economic History
Department of Economic History
London School of Economics
Houghton Street
London
WC2A 2AE
Tel +44 20 7955 7857
Fax +44 20 7955 7730
t.leunig@lse.ac.uk
http://www.lse.ac.uk/Depts/economic-history/people/leunig/leunig.htm

Abstract

This paper uses new product-specific, micro-level US data to show that New England had lower levels of productivity in cotton spinning than Lancashire, c. 1900, contradicting results derived by Broadberry from the Censuses of Production. The discrepancy stems from the Censuses' poor methods of aggregating heterogeneous yarn output. The finding that Britain – the labour-abundant country – has higher labour productivity contradicts the Rothbarth-Habakkuk model. We suggest Britain's industrial success stems from more intensive competition, manifested through external economies of scale and longer production runs. We finish with some speculative implications for British performance in the first and second industrial revolutions.

Keywords

Cotton
Spinning
Lancashire
New England
Productivity
Rothbarth-Habakkuk
Chandler
Rings
Mules
External economies of scale
Competition

I

As befits the leading industry of its day, the Lancashire cotton industry has been studied extensively, both by contemporaries and by economic and social historians. The resulting literature is prodigious, with a recent select bibliography running to 3000 items[2]. All periods are well studied, with different questions dominant for economic and social historians of different periods. For the period c. 1900, the key questions revolve around the causes and consequences of Lancashire's differences. Lancashire was the industry most attached to the spinning mule and the power loom, and least enthusiastic about the ring and automatic loom. It was the industry that grew by adding more and more firms, with little or no growth in firm size. The Lancashire cotton industry also remained vertically specialised almost beyond imagination. It is most often compared with its opposite number in New England, where firms were more likely to adopt the new (American-invented) technologies of the ring and automatic loom, to be large, and to be vertically integrated. Good summaries of the general literature can be found in Marrison, Mass and Lazonick, and Rose.[3]

Much work has been done both to explain Lancashire's technological choices, and to document the possible advantages of moving over to a system more similar to that prevalent in New England. Yet despite this volume of work, there is little that explicitly investigates which country had higher productivity in producing cotton goods. This is surprising, since detailed and reliable productivity estimates can be used to assess more accurately the effects of a number of aspects of cotton spinning that differed in the two countries. For example, following Marshall it is frequently claimed that the Lancashire cotton industry benefited from external economies of scale.[4] In addition, Lancashire workers, especially mule spinners, were renowned for high levels of skill and experience, which might reasonably be expected to lead to higher productivity.[5] Finally, the industry was highly competitive, in that it was characterised by many firms and extreme vertical specialisation. Modern empirical work increasingly finds that competition is an effective incentive mechanism for managers.[6] In contrast, others have claimed that larger US firms gained from internal economies of scale, and that vertical integration allowed the co-ordinated introduction of newer generations of machinery in both spinning and weaving.[7] Both the ring and the automatic loom offered considerably higher levels of capital productivity than the older technologies of mule and power loom. Further, compared with Britain, capital and especially labour in New England were relatively expensive compared with the cost of raw cotton and fuel, so we would expect manufacturers to economise on those factors, in line with the Rothbarth-Habakkuk hypothesis.[8] This again points to high levels of labour productivity in New England. We will use detailed estimates of productivity within the industry to assess the historical importance of these factors.

This paper begins by looking first at the Rothbarth-Habakkuk and Chandlerian frameworks, before contrasting the position of the two industries c. 1900. We then review the small secondary literature on Anglo-American productivity in cotton spinning, arguing that although Broadberry's work is clearly the best available, it is not, inherently, the best method available to assess productivity in this industry, and that the results are correspondingly hard to interpret. In section three we compile and compare four sets of micro-level productivity estimates, covering Lancashire rings, Lancashire mules, New England rings and New England mules. Section four sets out the implication of these results for work on productivity and analyses the likely causes of Britain's generally impressive performance. Section five then extends that analysis to offer a few more speculative comments on Britain's success in the first and second industrial revolutions, and section six concludes.

II

Any work setting out to compare Anglo-American productivity in the nineteenth century must begin with the Rothbarth-Habakkuk thesis.[9] At its simplest, it states that in land-rich America, labour was drawn to agriculture, so that industry became characterised by high capital intensity and by correspondingly high labour productivity. In contrast, land-poor Britain had abundant industrial labour, so industry was characterised by low capital intensity and low labour productivity.[10] This hypothesis has seen both theoretical and empirical challenges. Temin showed that the theoretical factor complementary assumptions underpinning the model are unrealistically restrictive,[11] while Field has shown that, empirically, the United States was not more capital intensive than Great Britain.[12] Despite these criticisms, the idea that the US was a labour-scarce economy can be reclaimed. First, as Field himself points out, if we define capital as machinery, so excluding buildings – of which the British stock far outweighed the American in the nineteenth century – it becomes possible to view the US as the more capital-intensive, labour-scarce economy.[13] Second, agricultural products that were used as inputs in manufacturing were relatively abundant vis-à-vis labour in the US. This encouraged US manufacturers to engage in labour-saving, resource-intensive methods of production that raised labour productivity.[14] For cotton processing this implies using ring spindles and automatic looms, machinery that saved on labour, especially skilled labour, but demanded better quality raw cotton. In the Rothbarth-Habakkuk model, different levels of labour productivity are the rational outcomes of economic actors responding to different historical circumstances.

Opposed to this strand of literature is one associated with Chandler in general, and particularly with Lazonick for the cotton industry. In this view, American manufacturing supremacy is primarily the result of innovation and investment in management, production and marketing. Mass marketing created standard demands that could be satisfied by mass produced goods. That in turn demanded good management organisation to create high-throughput production techniques and to ensure high levels of capital utilisation. This story is in some sense a-historical and a-national, in that the opportunity to make the three-pronged investment is seen as universal. The American experience, then, is one that others could have followed, and against which they may legitimately be judged.

We now turn to look at the two industries, which have strong similarities at the most aggregate level: notwithstanding cyclical fluctuations, both grew throughout the nineteenth century and until the outbreak of war in 1914. In both cases, the rates of growth slowed as the period went on, so that the period after, say, 1875 can be characterised as one of maturity. But the two industries did differ in three ways: market orientation, product mix, and industrial organisation,

At its simplest, Britain produced for export, whereas the US produced for domestic consumption. Exports accounted for 80% of British cotton output between 1880 and 1910, and Britain accounted for around three-quarters of world cotton exports.[15] Approximately one-half of British cloth exports, by volume, went to India, a quarter to other low-income areas, and one percent to the United States.[16] The US industry, in contrast, produced primarily for domestic consumers: the US Census described the export trade ‘as an accident rather than as an industry’.[17] Expansion was driven instead by the growing size of the US domestic market, in this, the era of peak immigration.[18] Exports, such as they were, came primarily from Southern rather than New England firms, with China the most important destination.[19]

The US imposed tariffs on imported cotton goods, with a nominal tariff of 37%. As ever, the nominal rate understated the effective rate of tariff protection, defined as the extent to which domestic producers could raise costs above those needed to survive under free trade. Hawke estimates that the effective protection rate for US cotton in 1904 was 238%, a prohibitive level, sufficient to keep imports of British cotton to trivially low levels.[20] It is worth noting that the New England cotton industry, on which this paper focuses, had no tariff protection against competition from mills in the US South –state level protectionism is precluded by the US Constitution.[21] The South emerged as an important cotton processing area in the postbellum era. In 1880 it had only one-twentieth as many spindles as the North, but just ten years later it produced as much coarse ("sub-20 count") cotton as the north.[22] The rise of the South, and its emphasis on long runs of standardised coarse goods, prompted a shift in New England production, with output of coarse yarn falling first as a proportion of output, and then from 1900 in absolute terms.[23] This shift by New England firms towards higher count yarn meant that New England mills – designed on Chandlerian lines to produce high quantities of standardised (coarse) goods – were forced to produce a wide variety of finer goods.[24] In his history of the Lowell's Boott Mills, Gross outlines how this attempt to avoid Southern competition proved difficult. Whereas in the 1880s sheetings and shirtings alone accounted for three-quarters of output, by 1902 the mill was producing 276 different types of cloth, using over 100 different yarns.[25] Gross finds that the use of a "Chandlerian" mill to produce short runs of many different products increased 'the difficulties of production manyfold'.[26]

Although New England mills were moving away from coarse goods, New England goods were, on average, still considerable coarser than those produced in Britain. The 1905 Census records that 37% of New England yarn output by weight was made up of sub-20 count yarn, with just 15% finer than count 40.[27] The equivalent figures for Britain, based on the machinery data assembled by Saxonhouse and Wright, are 19% and 35% respectively.[28] In simple terms, New England was twice as likely to be producing coarse yarn as Lancashire, and less than half as likely to be producing fine yarn. Despite these differences, both industries produced sizeable quantities of all types of yarn.

The two industries were organised differently: integrated spinning-weaving firms accounted for 87% of New England's spindles but only 21% of Lancashire's.[29] The effects of Lancashire's preference for vertical specialisation have been much investigated,[30] but here we note only that vertical specialisation increased the elasticity of demand for yarn. A specialised spinner lowering costs had three ways to increase sales: increasing the amount sold to weavers whom it already supplied, increasing the number of weavers to whom it sold, and by exporting (additional) yarn to foreign weavers. In contrast spinning departments in New England's integrated firms could not increase sales to their own weaving departments, whose demands were fixed by their number of looms, or make sales to other integrated firms, who purchased yarn from their own spinning sections, or by exporting yarn. As a result vertical integration lowered New England firms' incentives to engage in cost lowering innovations.

It is often perceived that British firms were smaller than those in New England. For spinners this was true only in the sense that New England firms were vertically integrated. New England firms did not contain more spindles than British firms: the average sizes were 55,000 and 68,000 spindles per firm respectively.[31] There was considerable variation in firm size in both places. The largest US firm, the Amoskeag, had 650,000 spindles, but was highly atypical: only two other New England firms had more than 200,000 spindles.[32] The largest British spinning company, Musgrove Spinning, had 460,000 spindles, but it too was atypical.[33] It is worth noting that very large mills were really combinations of several mills, each run, to all intents and purposes, as separate businesses.[34]

Only three authors, Lazonick, Clark and Broadberry, have calculated the level of labour productivity in the British and American cotton industry in the pre-war period. Their aims and methodologies are profoundly different, but none give entirely satisfactory results.

As part of his work on comparative industrial relations systems, Lazonick looks at mule spinners producing count 32 yarn.[35] He notes that British mill owners bought shorter staple raw cotton than their American counterparts. According to Lazonick, the use of inferior cotton reduced cotton costs, but lowered capital and labour productivity. After noting the difficulties in estimating comparative labour productivity, Lazonick writes that 'in the late 1890s output per "direct" worker-hour (that is, including auxiliary labor) in spinning no. 32s was at least 15-20 percent higher in Fall River than in Oldham.' He also argues that corrected for the higher proportion of skilled, experienced operatives in Lancashire, 'labor productivity in spinning 32s around the turn of the century was about 40 percent higher in Fall River than Oldham.'[36]

Lazonick gives no details as to how he derives his estimates, and his evidence is weak. He cites Taggart and Cramer's contemporary books on cotton mill management as sources for Oldham and for Fall River respectively, but neither gives data on output per worker, only on output per spindle. In addition, Cramer writes explicitly that his book is 'published for the Southern trade' rather than for New England.[37] Finally, Cramer's figure for output per spindle is only 6 percent higher than Taggart's for Lancashire.[38] In short, it is hard to take as reliable Lazonick's claim that Fall River mule spinners were either 15-20 percent or 40 percent more productive than their Lancashire rivals.

As part of his attempt to explain why the whole world is not developed, Clark assembles evidence on spinning productivity in cotton in Britain and the US.[39] He first assesses capital-labour ratios (which he calls 'labour efficiency'), before looking at capital-output ratios. He finds that US ring spinners tended 44% more spindles, but that British ring spindles were 8% more productive, from which we can deduce that the US had a labour productivity lead of 33% in ring spinning.[40] He does not produce explicit figures for mule spinning. We would not, however, want to put too much weight on this result. Clark's aim was to provide numbers with which to contrast manning levels in high and low wage countries, rather than to allow an Anglo-American productivity comparison; indeed it is noteworthy that he does not give an Anglo-American productivity figure. Instead he notes that his labour efficiency measure 'is contaminated by a number of differences between countries', namely 'differences in machinery types, different proportions of women and children and different types of yarn and cloth produced'.[41]

Broadberry's motives for measuring productivity in cotton spinning are different. Whereas Lazonick was motivated by specific questions about cotton, and Clark by questions of global magnitude, Broadberry is interested in the economy-wide productivity outcome of the interaction of Britain's and America's willingness to accept product standardisation on the demand side with differing levels of skills on the supply side.[42] Via the two alternatives of mass production and flexible production, these have implications for productivity in both the short and the long run. Broadberry uses Production Censuses in the two countries to assess productivity in each cotton industry as a whole, and, in an appendix, sub-divides the results into the spinning and weaving sections, with separate productivity results for each.[43] He also covers 28 other industries to give a comprehensive economy wide picture. His methodology is straightforward and generally robust. He takes data on the physical quantity of output and the number of workers directly from the Censuses for each country, and divides output by employment. For cotton, as for most other goods, output is measured by weight. For this period Broadberry uses the 1907 British Census and the 1909 US Census, and finds that productivity in the spinning section was 20 percent higher in the US than in Britain.[44] He notes that, overall, US productivity rose 3.3 percent between 1907 and 1909, which implies a best guess estimate of a 17 percent US productivity lead for cotton spinning in 1907.[45] Although the US is the leader in cotton spinning, its advantage in that sector is less than that in manufacturing as a whole, prompting Broadberry to conclude that 'Britain clearly did well in textiles'.[46]

The level of aggregation makes Broadberry's result hard to interpret. We have already noted that the product mix was very different in the two countries. Since heavier, coarse goods made up a higher proportion of US output, the use of weight as a measure biases the results in favour of the US. This makes Broadberry's result compatible with three scenerios, each with different implications for industrial leadership. First, the US may have led in the production of a given yarn using a given machinery type. Such a result would demonstrate the clear superiority of American manufacturers, in that they were able to produce more from any given piece of machinery. As an alternative, it may be that Lancashire's external economies of scale outweighed the internal economies available to US firms, so that Lancashire's productivity when using any given machine exceeded that of the US, but that the different mix of rings and mules in each country gave the US an overall lead in the production of any given yarn. We would still conclude that America's manufacturers were superior, but the story would not so much be one of greater managerial success, but instead a manifestation of the Rothbarth-Habakkuk thesis, with different factor prices leading firms in different countries to adopt different technologies, with different but inevitable productivity outcomes. A third option would be for Lancashire to lead in the production of any given yarn, including the different mix of rings and mules, but with this lead hidden by the greater preponderance of coarse yarn in US output. In this case it would be right to characterise the British as leaders in cotton spinning, because they were the more efficient producers of any given product. This leadership would be masked by different output mixes, caused by different demand structures. The aggregate nature of Broadberry's result does not allow us to say which of these three stories is correct, and it is for this reason that we characterise Broadberry's results as hard to interpret.

III

In theory, labour productivity is easy to calculate: total output is simply divided by total employment. In reality the process is not as straightforward because countries often produce different products, with different labour and capital requirements. Production Censuses are often used as a source of information on output. Censuses, however, operate at high and often crude levels of aggregation. For cotton, data availability leads both the UK and US Censuses to aggregate output by weight, even though, as the US Census itself acknowledges, 'the efficiency of spindles is measured by the length rather than the weight of their product'.[47] In the case of cotton spinning, however, we can do better than this, by avoiding the aggregation problem altogether. Micro-level output estimates for different types of yarn are readily available, allowing us to construct individual productivity estimates for each type (count) of yarn, from coarse to fine. This cannot be done for weaving, as cloth is more heterogeneous and harder to describe than yarn. It is worth noting in passing, however, that linear length, the measure of output used by the Census for cloth is, like weight, biased in favour of coarse cloth producers such as the United States. Each time the weaving shuttle inserts the weft yarn into the warp it creates a length of cloth equal to the diameter of the weft inserted, so a weaver using coarse yarn creates more length with each shuttle pass. Unfortunately it would require much more evidence than is available to quantify the magnitude of this bias with any degree of reliability, and, as a result, we limit our attention to cotton spinning.

The division of cotton yarn into coarse and fine yarns was not a division into mass-produced and craft-produced yarns. All cotton yarns, even the finest counts, were mass-produced. Some consumers preferred coarse yarn to fine, even at the same price, because coarse yarns were better for some uses, such as sacking. To economists, different counts of yarn are examples of horizontal differentiation, that is, goods where consumers' choices depend on the use they wish to make of the product, rather than on their income.[48]

As well as disaggregating yarn output to the level of individual counts, we also construct separate productivity estimates for ring and mule spinners in each country. This in turn will allow us to separate out the three influences on productivity which we identified earlier: different ratios of coarse to fine yarns, different ratios of ring to mule use and different factor cost conditions under which firms operated. The last includes the degree of competitive pressure and the availability of internal and external economies of scale.

We now construct four separate labour productivity series, for Lancashire rings, Lancashire mules, New England rings and New England mules. We choose to restrict our analysis to New England rather than to the US as a whole because writers seeking to understand the cotton industry most often compare Lancashire with New England. These were the sectors that had led the move to industrialisation, and by 1900 both these sectors had long histories of spinning, and both faced the same challenges of new technologies. In all cases our figures will apply to the period *c.* 1907, although inevitably there is some variation around that date. Each series will give productivity per week for as wide a range of counts as the data allow. The denominator will be workers directly involved in the spinning process itself, that is, spinners, piecers and doffers, but excluding supervisors, auxiliary staff such as cleaners, and workers in preparatory processes, such as carders.

Although explicit data on labour productivity are not common, evidence on both output per spindle and spindles per worker is common, so that we can easily construct data for output per worker, using the identity that states that labour productivity is the product of capital productivity and the capital to labour ratio. Algebraically,

$$(Q/L) = (Q/K).(K/L)$$

where Q is the amount produced, L the amount of labour and K the amount of capital, in this case measured by the number of spindles. As mentioned, estimates both of output per spindle and of spindles per worker are readily available; we begin with output per spindle, first in Lancashire, then in New England, before looking at spindles per worker.

We use Taggart's comprehensive 1923 series for output per mule and ring spindle in Lancashire. These series are compatible both with Winterbottom's 1907 series (average deviations of 0.1% and 1.3% for mules and for rings respectively) and with data on British mule productivity in the 1912 US Tariff Board Report (average deviations of 1%).[49] We favour Taggart's series because they are the most comprehensive. Taggart's series are not actual production data, but rather an estimate of 'good average production'[50] for a book described as a 'practical and orthodox statement of present mill working.'[51] The same is true for Winterbottom's series. Both books were written for cotton managers and overlookers, and there seems no reason to think that these series are biased in either direction. In addition, as mentioned, the series are exceptionally close to the actual productivity figures presented by the Tariff Board Report. We therefore feel confident in using them as a measure of actual output per spindle.

There is no equivalent source to Taggart for New England.[52] Instead we use new archival evidence drawn from the surviving production records of three large New England firms: the Amoskeag, the Lyman and the Naumkeag. These records, kept in the Historical Collections section of Harvard Business School's Baker Library, give the actual output per spindle at a range of counts. We have 43 observations for mule spinning and 24 for ring spinning. We use regression analysis to estimate a single continuous series for New England mules and a corresponding series for New England rings. Both the data and the procedure are given in appendix one.

There is obviously a concern as to whether these three firms were representative of New England. Both industry-wide and other firm-level observations suggest that they were. At the industry-wide level the 1909 US Census reported New England yarn output for three count categories, sub-20, 21-40 and supra-40.[53] Dividing these total output figures by our estimates of output per spindle gives an estimate of the number of spindles in place. This estimate is just 1% different to the actual number of spindles given in the Census, telling us that our sample of firms closely mirrored average productivity in New England. The full details are again given in appendix one.

Our estimates are also in line with observations from two other independent sources. The 1912 Tariff Board Report recorded output of 1.12 pounds (count 32 warp) and 0.616 pounds (count 50 weft) per ring per 56 hour week for a new US mill.[54] Our estimates are 1.07 and 0.55 pounds respectively: an 8% difference between new and average machinery seems reasonable. Young recorded that a Lowell mill produced 1.35 pounds (count 28 warp) per ring per 58 hour week; our estimate is 1.34 pounds for a week of that length.[55]

Figure one gives output per ring and per mule spindle in each industry. It shows that, as we would expect, ring spindles had higher levels of capital productivity than mule spindles, especially at lower counts. It also shows that, when using a particular machine to spin a particular count, Lancashire generally had higher rates of capital productivity than did New England. This is true for rings at all counts, and for mules at all counts up to and including count 60. That British rings were more productive than US ones is less controversial than it may at first sight appear; the same result was found by the 1912 Tariff Board Report, which looked at output in new mills, and by Clark.[56]

Figure 1 [Output per spindle (pounds weight per 100 spindles per 55.5 hour week)] about here

We now move on to the less straightforward process of assessing the capital to labour ratio for each type of machine in each country. As mentioned, we look at those directly involved in the spinning process and do not include auxiliary labour such as supervisors or cleaners, nor those involved in the earlier preparatory stages, such as carding. In both countries ring spinners worked alone rather than in teams, but had doffers to remove the completed bobbins. In contrast mule spinners were responsible for their own doffing, but were assisted by piecers – two per spinner in Lancashire and one per spinner in New England.[57] In order to ensure that the comparison is fair, we include ring doffers and mule piecers, as well as the spinners themselves.

The 1905 US Census stated that each New England mule spinner tended 1124 spindles. All were recorded as aged over sixteen, indicating that piecers were not included. Since each New England mule spinner had one piecer to assist them, each mule spinning operative was responsible for 562 spindles. The UK Census did not publish equivalent data for British mule spinners, but decadal data on spindles per new mule in Oldham and Bolton is given in Jewkes and Gray. Mules lasted around fifty years, which combined with growth rates in the industry, implies that the average mule in 1907 was installed *c.* 1886.[58] In that year new mules averaged 1044 and 986 spindles in Oldham and Bolton respectively, giving an average of 1032 spindles for Lancashire.[59] A three-person mule team, responsible for a pair of mules, would have tended 2064 spindles per team, that is 688 spindles per operative, a figure 22 percent higher than in New England. This lead fits in well with the qualitative literature, which stressed the level of skill of Lancashire's mule spinners.[60]

The 1905 US Census states that New England ring spinners tended 522 spindles each.[61] The relatively high proportion of males recorded tells us that the Census includes doffers in this definition of spinners, explaining the low capital to labour ratio compared with the figures given by, say, Copeland.[62] Again, the UK Census does not provide equivalent information for Lancashire. We do, however, know both average earnings and the wage rate per spindle, so we divide the former by the latter to find the number of spindles per ring spinner.[63] We also know that there were on average 61 doffers per 100 spinners, allowing us to express our capital-labour ratio estimates on a per operative basis.[64] The results for Lancashire ring spinners are given in table one. As can be seen, the capital-labour ratio rose with the count, because 'there is less work involved in tending 100 spindles producing fine yarn than the same number of spindles producing coarse yarn.'[65] No evidence exists on whether fine yarn spinners tended more spindles in New England as in Lancashire. Because of this lack of evidence we consider two cases, the first assuming that all New England spinners tended 522 spindles, irrespective of count, the second assuming that the capital-labour ratio rose with the count, as in Lancashire. In the former case New England operatives tended between twenty and one hundred per cent more spindles per operative, depending on the count, in the latter a consistent thirty one per cent more spindles than did Lancashire ring spinners.[66] Again this is plausible: Clark finds that US ring spinners tended forty four percent more spindles than their Lancashire counterparts.[67]

TABLE 1 [Ring spindles per operative, Lancashire] about here

Now that we have data on output per spindle and spindles per worker, it is a matter of simple multiplication to calculate output per worker. The results are given in Figure two. We can see that Lancashire mule spinners had consistently higher productivity than Lancashire ring spinners, whereas in New England the reverse was true for all counts up to 60. This is in keeping with contemporaries' observations: Copeland, for example, noted that English mule spinners high rates of productivity meant that 'their high earnings do not constitute a comparatively heavy burden upon the English employers'. He attributed this to their adeptness, and stated that mule spinners from elsewhere would not be able to command their earnings, even were they to move to Lancashire. It is worth noting that had Britain's transition to ring spinning been faster, aggregate productivity would have fallen. In some sense this should not surprise us: mule spinners were better paid than ring spinners, investments in mule spinning continued to be profitable in this era, so the implication has to be that mule spinners were more productive than ring spinners.[68]

Figure two also shows that Lancashire mule operatives were unambiguously more productive than any other group. It also shows that at low counts New England ring spinners were more productive than Lancashire ring spinners, with the positions reversed at higher counts. This result is driven entirely by the assumption that the number of spindles per New England worker did not vary with the count spun. Were it to have done so, then ring spinners in the two countries would have had almost identical productivity for all counts before the mid-50s, with Lancashire opening up a lead at higher counts.

Figure 2 [Output per operative (pounds weight per 55.5 hour week)] about here

Three pieces of independent evidence support the estimates given in figure two. First, we can calculate unit labour costs for each method of production from these productivity figures and data on workers' wages. The details are given in appendix two. As expected, the labour cost advantage of using rings is lower in Lancashire than in New England. Taking into account the extra cost of the longer staple raw cotton required for ring spinning, we find that the costs of rings and mules were finely balanced in Lancashire for all counts less than 40 with mules dominant thereafter, but that rings dominated for all except higher counts (at least 60) in New England. This is in line with observed investment behaviour.

Second, data drawn from the 1912 US Tariff Board Report on Cotton Manufactures, presented in table two, supports the notion that Lancashire mule spinners were more productive than New England ring spinners. The Tariff Board found that the average labour cost of producing a given type of yarn was thirty per cent lower when using mules in the UK than when using rings in the US, implying that UK wages were thirty percent lower, that US workers were thirty percent less productive, or some combination of the two.[69] US textile workers (excluding salaried officials) were paid an average of $304 p.a. in 1905, and British cotton workers £48 ($233.60) p.a. in 1906, implying that British firms had ten percent higher productivity than that of their US rivals.[70] The Tariff Board itself concluded that 'the output per spinner per hour in England is probably as great or greater than in this country'.[71] The data in the Tariff Board cannot be compared directly with the data given here, since the former covers all of the US, rather than just New England, and includes all processes from the raw cotton arriving in the factory to being spun, but it does show that contemporaries were aware that Lancashire's mule spinners were highly productive.

Table 2 [Estimates of Labour Productivity using Tariff Board Report data] about here.

Third, firm-level evidence survives in the form of the Lyman mills mule spinners' wage list. This gave the wage per 100 pounds of yarn produced. Multiplying these wages by the productivity levels in figure two, and remembering that mule spinners were paid for gross output, that is, including the output of their piecer, gives an estimate of earnings of between $9.56 and $12.48, depending on the count spun. We know in fact that Lyman mule spinners earnings averaged $10.18 in 1909 and $11.99 in 1913, both within the range given by our productivity estimates.[72]

Having established the productivity per worker on each machine, we now move on to look at which industry had the lead in producing any given type of cotton, using the production techniques typical in that country. By this we do not simply mean whether

Lancashire mule spinners were more productive than New England ring spinners – figure two shows that this was the case – but rather whether producing, say, 100 pounds of count 32 yarn took fewer worker-hours in one country than the other, using the representative mix of workers and machinery producing that yarn in each place. We know from the Census that, overall, sixteen percent of Lancashire's spindles were rings and 84 percent were mules.[73] Saxonhouse and Wright give the distribution of each by count, from which we can calculate the proportion of each count of yarn produced on rings and mules.[74] Since we are interested in labour productivity, we convert the proportion of yarn produced on rings and mules into the proportion of yarn produced by ring operatives and mule operatives, using the capital-labour ratios assembled earlier. We do the same for New England, using the Census for the overall ratio of rings to mules, and the Amoskeag, Lyman and Naumkeag mills data in appendix one to find the distribution of each type of spindles by count.[75] The distribution of both spindles and operatives is given in table three. It is worth noting that mule spinning's higher capital to labour ratio, especially in Britain, mean that that percentage of mule operatives is lower than the percentage of mule spindles at any count.

Table 3 'Percentage of spindles and operatives by count' about here

Combining the data in table three with that in figure two allows us to construct overall figures for output per operative. Figure three gives New England data both on the assumption that all ring operatives had equal numbers of spindles, and in addition, where the result is materially different, on the assumption that the capital to labour ratio for New England ring operatives varied with the count. Figure three shows that average labour productivity was higher in Lancashire for all counts of 20 and over, with a sizeable lead for counts of 30 and over. This is true whether or not the New England ring capital-labour ratio varied by count. For coarser yarns that assumption proves to be crucial: if the capital-labour ratio was constant, then New England has a labour productivity lead of seven percent at count 16, if the ratio did vary, then Lancashire has a lead of nine percent. The most sensible conclusion that can be drawn is that the two industries were broadly equal for coarse yarn, that Lancashire had a slight productivity lead for counts in the 20s, and a clear lead for yarns finer than 30.

Figure 3 [Output per operative (pounds weight per 55.5 hour week)] about here

IV

These results show that aggregation techniques used in the Census can make it an unreliable source for productivity estimates. Based on Production Censuses, Broadberry found that United States labour productivity in cotton spinning was 17 percent higher than in Britain. Since this paper looks only at New England – where capital-labour ratios were sixty percent higher than in the United States as a whole – we would expect to find that New England's labour productivity was much higher than in Britain. Instead we found that the two industries had similar productivity for low count yarn, and that New England had lower productivity for all counts above 20. The problem is that the Census aggregated recorded output by weight, which is poorly suited to comparisons across space or time if the output mix is different. We mentioned earlier that the method of aggregation for weaving, linear length, is also biased towards coarse cloth producers like the United States, although the evidence does not exist to allow us to make an accurate estimate of the extent of this bias. A re-examination of other industries, paying careful attention to differences in product mix, might lead to further revisions in Anglo-American productivity comparisons. For example, although both writers use the Censuses as their sources, and both agree that the United States was the clear productivity leader, Magee finds that the US labour productivity lead in paper making was 92% in 1907, considerably lower than the 162% lead found by Broadberry.[76]

Broadberry, following Sandberg, ascribes the relatively good performance of the British cotton industry to the continuing viability of craft production in Britain in the face of US mass production.[77] This is not an adequate characterisation of the two industries, both because mules were a form of mass production, and because Lancashire was broadly as productive at ring spinning as New England. We argue instead that the most plausible proximate cause of Lancashire's success was external economies of scale, and that this reflects a deeper underlying advantage: vigorous competition.

Firms in Lancashire gained directly from external economies of scale, whereby costs fell as the size of the industry increased. External economies of scale took two forms. First, to quote Marshall's dictum, 'The mysteries of the trade become no mysteries; but are as it were in the air.'[78] Located close together, frequent contact between mill owners and between workers was inevitable. Publications such as Worrall's Directory gave firms good access to new inventions and modifications that could raise productivity. In 1902, for example, Worrall listed 62 machinery makers, 36 belt and strapping manufacturers, and 31 suppliers of grease and tallow. Small but useful innovations could be readily disseminated. Marshall also argued that specialisation allowed Lancashire cotton firms to concentrate on a limited range of goods.[79] In contrast Parker, a management consultant advising Lowell's Boott Mills in 1902, arguing that they had 'attempted to make too great a variety of yarn and cloth',[80] depressing productivity. Copeland noted that such specialisation was more common in Lancashire than in the United States.[81] In this sense, it is possible to conceptualise the Lancashire cotton spinning industry as the more Chandlerian. Although it was not vertically integrated, British firms had more spindles, and proved better able to produce long runs of standardised output.

External economies of scale were not, however, exogenous to the industry, but were instead the result of conscious decisions as to where to locate.[82] Increasingly those decisions made the industry more concentrated, both in Lancashire, and within Lancashire.[83] For that reason we characterise external economies of scale as a proximate cause of Lancashire's advantage, and argue that it was strong competitive pressures that forced firms to locate in areas offering high external economies of scale.

Modern empirical economics is increasingly consistent in favouring the Hicksian critique of monopoly power. Nickell's 1996 paper is perhaps the most sophisticated and convincing work in the area. He uses panel data for British industry for 1972-86 and finds that 'competition, measured either by increased numbers of competitors or by lower levels of rents, is associated with higher rates of TFP growth'.[84] The Hicksian notion that the 'best of all monopoly profits is a quiet life' implies that monopolist owners substitute out of costly effort and into pleasant sloth, or, more likely, that their managers and workers do so, unobserved by owners. Competition provides owners with information by which to judge their managers – namely the performance of rival firms. Knowing this to be so, managers work harder. The introduction of competitive tendering into British refuse collection industry in 1988 provides a textbook example. Previously municipalities had collected refuse themselves, as local monopolists. When competition was introduced, bids – including those from internal organisations – averaged 19.5% less than the previous cost, revealing to principals the extent of their agents' 'quiet life'.[85]

We can measure competitive pressure by the uniformity of an industry's costs. If competition is effective, prices will be bid down, and high cost firms must cut costs or exit the industry. As a result, all surviving firms will have similar cost levels, so that the uniformity of costs acts as a measure of the degree of competition. The Tariff Board recorded the cost of producing twelve different yarns in each country, with a total of 87 observations for the United States and 79 for the United Kingdom.[86] The average co-efficient of variation in the costs of producing each yarn was 75% lower in the United Kingdom as in the United States, demonstrating greater levels of competitive pressure in the UK. We argue that it is this greater competitive pressure that forced the UK industry to pursue the cost minimising strategies of locating close to other firms, and rigorously adopting best production practise.

V

The idea that competition increases the pressure to be efficient may help to explain why Britain was so much more successful in the first than in the second industrial revolutions. Both of Britain's two early productivity successes – textiles and agriculture – were characterised by low minimum efficient scale and high levels of competitive pressure.[87] Textile firms faced competition from other firms within Britain, and, through exporting, were exposed to latent competition from foreign firms. Good transport links ensured that agriculture also faced strong competition from within Britain, and as a major food importer, from abroad. Prior to the first world war, agricultural imports constituted 41% of total British imports, providing vigorous and sustained competition for British farmers.[88]

Neither textiles nor agriculture were at the forefront of the second industrial revolution, a revolution characterised by far greater possibilities for internal economies of scale. The classic example of that revolution was 'the signature product of the twentieth century', the car.[89] In 1913 the output of the British motor industry was fewer than 30,000 vehicles,[90] less than one-tenth the amount produced in the US.[91] Not only was the US market large enough for Ford to gain internal economies of scale by moving to mass production, but crucially it was large enough to sustain other firms as well, ensuring that Ford faced continual competitive pressure. Ford out-produced General Motors fourfold in 1913, but in that year GM still produced more than 50,000 cars, and was in a position to challenge Ford for industry leadership.[92] The size of the British domestic market was too small for Britain to have a car firm that was simultaneously large enough to gain available economies of scale, and to face sustained competitive pressure from at least one another firm. Such a position would only have been possible had British car producers been able to follow British textile manufacturers in exporting a sizeable proportion of their output. But the countries to which Britain sold textiles, such as India, China, and Latin America were too poor to buy cars, and, prior to 1914, high-income countries generally had high tariff barriers. As a result the structure of global tariff barriers biased British industry towards first generation industrial products.

Only America had a market large enough to offer second industrial revolution firms the possibility of internal economies of scale that would raise productivity and lower unit costs, and the guarantee of market discipline that would force them to make those investments. Furthermore, the unity of the US market was protected by the United States Constitution itself, which explicitly forbids the creation of tariff and non-tariff trade barriers between States. The result was a surging US productivity lead in the first half of the twentieth century. Only when trade between rich nations increased from 1945 were small open economies with high levels of human capital able to begin to close the productivity gap with the United States.[93] This suggests that it would be useful to consider the concept of 'minimum efficient market size' as a market large enough not only to allow one firm to reach the minimum efficient scale, but to ensure that that firm faces competition sufficient to give it the incentive to produce at the lowest cost in the short run, and to engage is activities to reduce costs in the long run.

VI

This paper finds that prior to the First World War Britain generally had higher levels of productivity in cotton spinning than did New England. This is true both on a 'like for like' basis, when comparing productivity using the same type of machinery, and when comparing productivity on the mix of machines that were typically used in each industry. This result is surprising since Britain was the labour-abundant country. It indicates that, in cotton spinning at least, it is correct to characterise Britain as the industrial leader. Britain's success was a function of high levels of competition, which forced firms to produce efficiently. This led firms to locate close together to take advantage of external economies of scale. By doing so they reinforced and increased those economies, raising potential productivity levels. In contrast New England lags behind Britain in productivity for all except coarse counts. We attribute this to the failure of New England firms to create long standardised runs of medium and fine counts of yarn, and to the survival of a tail of inefficient firms.

Since Britain was the labour-abundant country, higher rates of labour productivity represent a challenge to the Rothbarth-Habakkuk model. We argue that challenge can be understood if we take the Rothbarth-Habakkuk model as showing what will happen under different factor conditions assuming equal levels of competitive pressure, but that weaker competitive pressure in the labour-scarce country may allow sufficient x-inefficiency to eliminate and even reverse its 'natural' productivity lead.

The New England industry is sometimes held up as the more developed, Chandlerian industrial form. The finding that New England firms had lower productivity could be seen as a criticism of the Chandlerian paradigm in this industry. In fact we must be cautious in any such conclusion, for although British firms were far less likely to be vertically integrated than their New England counterparts, they had on average more spindles than New England firms, and, as mentioned, achieved longer production runs of any given yarn. It possible, therefore, to argue that it is the Lancashire industry, not the New England one, that is the more Chandlerian.

Our results are broadly in line with the conclusions of the contemporary Tariff Board Report, but contrasts with Broadberry's findings, based on the Censuses of Production. We argue that this casts some doubt on the use of Production Censuses for productivity comparisons. They are tremendously useful in that they aggregate production into readily comparable categories. But we need to be sure that the aggregation techniques are appropriate, and do not bias the comparison in favour of one country or another. If that condition is satisfied then they remain a useful guide to comparative productivity levels, but if it does not, then they can lead to misleading results.

(Figure 1 supplied separately)

TABLE 1
Ring spindles per operative, Lancashire

Count not less than	Weekly earnings (pence)	Weekly wages per 100 spindles (pence)	Spindles tended per spinner	Spindles tended per operative
8	182	43.243	421	261
10	182	39.783	457	283
12	182	37.188	489	303
14	182	33.729	540	335
17	182	31.134	585	363
22	182	29.405	619	384
29	182	28.107	648	402
37	182	26.811	679	421
43	182	25.945	701	435

Sources. Weekly earnings, *1906 Enquiry*, p. 30; Weekly wages per 100 spindles tended, Jewkes and Gray, *Wages*, p. 121.
Notes. ‘Operative’ includes doffers.

(Figure 2 supplied separately)

TABLE 2

Estimates of Labour Productivity using Tariff Board Report data

	Wages	Unit Labour Costs	Output per worker
US ring spinning firms	100	100	100
UK mule spinning firms	76.84	69.89	109.95

Sources: wages: 1905 US Census, p. 14; 1906 Earnings Enquiry, p. xviii; unit labour costs, Tariff Board Report, pp. 417-420.

TABLE 3
Percentage of spindles and operatives, by count

	Lancashire				New England			
	Rings		Mules		Rings		Mules	
	spindles	operatives	spindles	operatives	spindles	operatives	spindles	operatives
<20	37	56	63	44	90	91	10	9
21-30	47	61	53	39	89	90	11	10
31-40	21	31	79	69	77	79	23	21
41-60	6	10	94	90	62	64	38	36
>60	1	1	99	99	40	42	60	58

Sources. Spindles: Lancashire: 1907 UK Census and Saxonhouse and Wright 'New evidence', p. 511, data for 1878-1906; New England: 1909 US Census and appendix one.
Operatives: see text, for New England we assume constant ring capital-labour ratios. If New England capital-labour ratios varied with the count spun, the ring operatives column would read 94, 93, 83, 68, 44

(Figure 3 supplied separately)

APPENDIX 1: CALCULATING CAPITAL PRODUCTIVITY RATES FOR NEW ENGLAND

Data on output per spindle per week are taken from production records for the Amoskeag, Lyman and Naumkeag mills, kept in the Historical Collections of Harvard Business School's Baker Library.[94] We have 43 observations for mule spinning, and 24 observations for ring spinning. The mule data cover counts 12 to 160, while the ring data cover counts 13 to 90. All data are for a 58 hour week.

TABLE 4a
Output per spindle: mule spinning

Count	Output	Count	Output	Count	Output
12	176	39	64.5	80	29.5
17	136	40	60	80	27.5
20	121.9	40	68	85	28.5
23	111	40	65.8	85	26.5
23	99.9	45	51.9	87	26
25	98.9	45	55	90	27.3
25	105.2	48	45	90	25
28	84.3	50	50	100	23.3
30	79	55	57	100	20
31	80	55	45.5	110	15
33	80	60	40.6	125	10
34	75	65	36.3	130	15.7
35	69.1	70	33	160	10
38	55	75	30.7		
38	70.4	75	27		

TABLE 4b
Output per spindle: ring spinning

Count	Output	Count	Output	Count	Output
13	320.4	25	185.2	35	104.4
16	257	26	153.6	35	116.2
16	323.8	28	116.7	36	86.7
18	181.7	28	127.2	40	79.9
19	238	29	116.6	50	67
22	200.9	30	98.2	60	45
23	171.7	32	105.9	70	32
24	130.3	34	90.5	90	24

We regress output on count to generate capital productivity series for mules and for rings that are both smooth and complete. Graphs of the actual and estimates lines are given below.

TABLE 5
Estimates of New England mule and ring output per spindle

	Mule spindles	Ring spindles
Intercept	-9.2	-39.9
	(4.9)	
1/count	3141	4861
	(25.6)	(16.9)
$1/count^2$	-11079	
	(7.0)	
Adj R^2	0.99	0.93
SE	4.0	22.3
F	1704	286

OLS regression performed using Stata; t-statistics in parentheses. The $1/count^2$ term was not significant in the ring spindle regression and has been omitted.

Figure 4

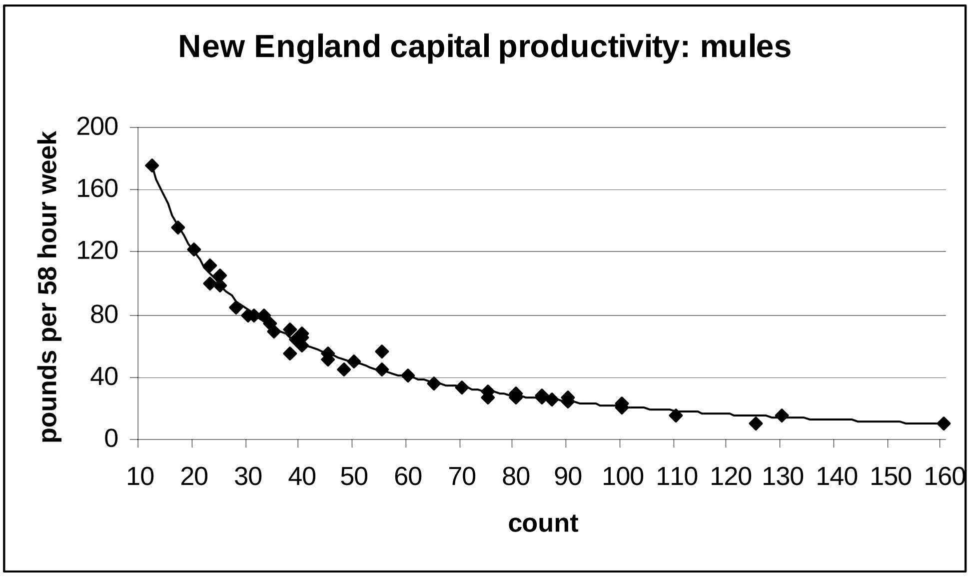

Figure 5

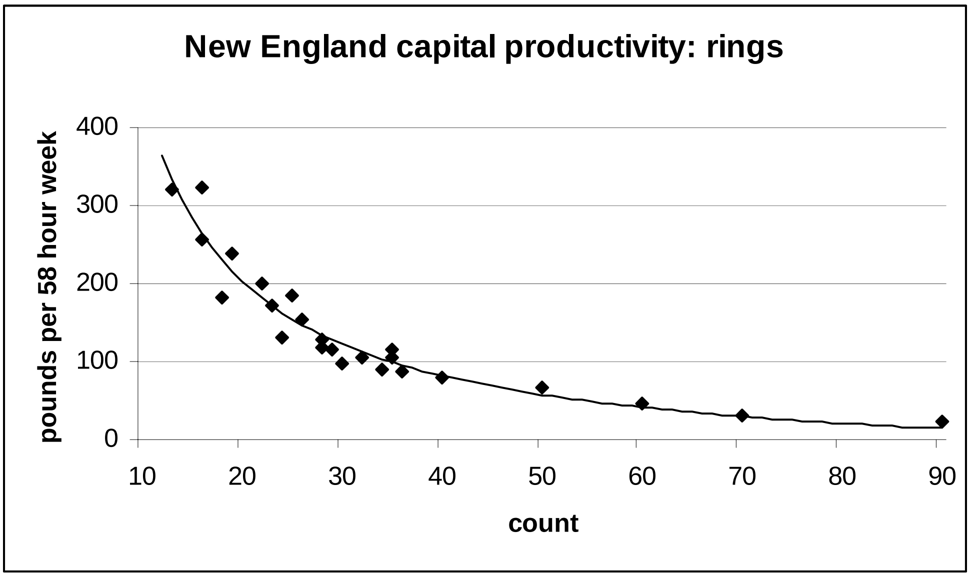

TABLE 6
Reconciling New England estimated capital productivity figures with aggregate spindle numbers and aggregate output

Counts	Annual output (thousand lbs)	Estimated spindles (thousands)
Sub 20	290,135	1,955
21-40	461,031	8,174
41+	114,721	5,428
Total	865,888	15,557
Actual spindles		15,384
Productivity underestimate		1.1%

Notes:
We assume that spindles are distributed uniformly within bands. We define sub-20 as 8-20 and supra-40 as 40-80.

Sources:
Output and actual spindleage, 1909 US Census, pp. 54-55.
Ring and mule output per 100 spindles per week, from figure 1
For this calculation we assume New England mills worked a 49.9 week year, in line with the UK, 1906 Enquiry p. xix.

APPENDIX 2 USING UNIT LABOUR COSTS AS A CHECK ON PRODUCTIVITY

Unit labour costs can be used to check our relative productivity numbers within each country. High tariff barriers mean that comparing unit labour costs across the two countries cannot tell us anything about relative level of productivity in each. Within both countries we expect ring unit labour costs to be lower than mules unit labour costs, with a wider margin in New England. We can also compare the unit labour cost saving from adopting rings with the additional expense of buying longer staple raw cotton needed for ring spinning. Since both rings and mules were used extensively for counts below 40 in Lancashire, we expect labour savings on rings to broadly equal the additional raw cotton cost for these counts, with mules the more cost efficient option thereafter. In New England, by contrast, we expect labour savings to dominate the additional raw cotton expense for all except high counts. Tables seven, eight and nine show that all of these predictions are born out, suggesting that our assessment of the relative productivity of ring and mule spinners in each country is accurate.

TABLE 7
Lancashire unit costs (d/lb)

	Mule labour cost	Ring labour cost	Labour cost saving	Additional raw cotton cost	Overall advantage to rings
16	0.2	0.16	0.04	0	0.04
32	0.42	0.30	0.12	0.12	0
40	0.56	0.39	0.17	0.25	-0.08
60	1.01	0.69	0.32	0.50	-0.18

Sources: Wages: 1906 Enquiry, pp. 29-31; productivity: figure two; raw cotton premiums: Winterbottom *Calculations*, pp. 235-236.

TABLE 8
New England unit costs, constant spindles (c/lb)

	Mule labour cost	Ring labour cost	Labour cost saving	Additional raw cotton cost	Overall advantage to rings
16	1.07	0.44	0.63	0	0.63
32	1.97	1.04	0.93	0.25	0.68
40	2.47	1.43	1.04	0.50	0.54
60	3.84	2.84	1.00	1.00	0

Sources: Wages: Chas Pidgen ‘Wages in Massachusetts Mills’, HBL Tremont and Suffolk Collection, Misc papers, clippings; productivity: figure two; raw cotton premiums: Winterbottom *Calculations*, pp. 235-236.

TABLE 9
New England unit costs, count varying spindles (c/lb)

	Mule labour cost	Ring labour cost	Labour cost saving	Additional raw cotton cost	Overall advantage to rings
16	1.07	0.53	0.55	0	0.55
32	1.97	1.03	0.94	0.25	0.69
40	2.47	1.35	1.12	0.50	0.62
60	3.84	2.60	1.24	1.00	0.24

Sources: Wages: Chas Pidgen 'Wages in Massachusetts Mills', HBL Tremont and Suffolk Collection, Misc papers, clippings; productivity: figure two; raw cotton premiums: Winterbottom *Calculations*, pp. 235-236.

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[2] Wyke and Rudyard, *Select Bibliography*

[3] Marrison, ‘Indian summer’, Mass and Lazonick, ‘State of the debates’ and Rose, *Firms, networks and business values.*

[4] Marshall, *Industry and trade* and *Principles*, Farnie, *English cotton industry*, p. 35, Broadberry and Marrison, ‘External economies’.

[5] Copeland, *Cotton industry,* pp. 73-3.

[6] See, for example, Nickell, ‘Competition’.

[7] Lazonick, *Competitive advantage,* p. 154

[8] Copeland, *Cotton industry,* p. 317, pp. 298-300, 286, Young, *American cotton*, pp. 12-13, Broadberry, *Productivity race*, pp. 77-80.

[9] Rothbarth, ‘Causes’, Habakkuk, *Technology*.

[10] O’Brien, ‘Path dependency’.

[11] Temin, ‘Labour scarcity’.

[12] Field, ‘Unimportance’.

[13] Ibid.

[14] Ames and Rosenberg, 'Enfield'.

[15] Robson, *Cotton industry*, p. 4, Marrison, 'Indian summer', p. 248.

[16] Marrison, 'Indian summer', p. 250

[17] 1905 US Census, p. 35

[18] Rose, *Firms, networks and business values*, p. 179; Atack and Passell, *New Economic View*, p. 233.

[19] Burgy, *New England*, pp. 211-212; 1905 US Census, tables 1, 3, 4, pp. 32, 35, 36; Galenson, *Migration*, p. 37.

[20] Hawke, 'Tariff', p. 90.

[21] Article 1, section 9 clause 5 and article 1, section 10, clause 2., see U.S. House of Representatives, URL: http://www.house.gov/Constitution/Constitution.html.

[22] Copeland, *Cotton Industry*, p. 34; Galenson, *Migration*, p. 5.

[23] Burgy, *New England*, p. 184, Rose, *Firms, networks and business values*, p. 184.

[24] Scranton, *Figured Tapestry*, p. 226, Rose, *Firms, networks and business values*, pp. 184-185.

[25] Gross, *Boott*, p. 44.

[26] Ibid., p. 93

[27] 1905 US Census, p. 48

[28] Saxonhouse and Wright, 'New evidence', p. 511. To convert from spindles to weight, I make the standard assumption that 1 ring equals 1.45 mules, and assuming 14 as the average count for sub 20 yarn, 25 for 21-30, 35 for 31-40, 50 for 41-60 and 75 for >60. Although different assumptions will give slightly different results, the overall conclusion that Lancashire produced less coarse yarn and more fine yarn cannot be disputed.

[29] 1905 US Census p. 55, Copeland, *Cotton industry*, p. 321, from Worrall's Directory.

[30] Marrison, 'Indian summer'.

[31] 1905 US Census p. 55. The figure is for integrated spinners only, including specialised spinning firms lowers the average to 51,000. Lancashire: Copeland, *Cotton industry*, p. 321, from Worrall's Directory.

[32] Copeland, *Cotton industry*, p. 142.

[33] Ibid., p. 322.

[34] Ibid., p. 142.

[35] Lazonick, 'Production relations', *Competitive advantage.*

[36] Lazonick, 'Production relations', 1981, pp. 509-510.

[37] Cramer, *Useful information*, pp. 152-157.

[38] Ibid., pp. 152-7, Taggart, *Cotton Mill Management*, p. 155.

[39] Clark, 'Why?'.

[40] Ibid., pp. 152, 154.

[41] Ibid., pp. 150.

[42] Broadberry 'Comparative productivity', *Productivity race.*

[43] Broadberry 'Comparative productivity', p. 541.

[44] Ibid., p. 541.

[45] Ibid., p. 523.

[46] Broadberry, *Productivity race*, p. 157.

[47] 1905 US Census, p. 53.

[48] Broadberry, *Productivity race*, pp. 24-5, Tirole, *Industrial organization*, pp. 96-7, Hotelling, 'Stability'.

[49] Taggart, *Cotton mill management*, pp. 155-6, 202-3, Winterbottom, *Cotton yarn calculations* pp. 204, 213, US Tariff Board *Report*, p. 411.

[50] Taggart, *Cotton mill management*, pp. 155.

[51] Ibid., pp. v.

[52] The Tariff Board Report does distinguish between New England and the South, does not cover mules, and its ring series is taken from the Whitin Machinery Makers catalogue, rather than representing actual output data.

[53] 1909 Census, p. 54

[54] US Tariff Board *Report* pp. 800, 804.

[55] Young, *American cotton*, p. 28.

[56] US Tariff Board Report, pp. 800, 811, Clark, 'Why?', p. 154.

[57] Copeland, *Cotton industry*, p. 299.

[58] Sandberg, 'Remembrance', p. 388, Lazonick, 'Reply', p. 394, Robson, *Cotton industry*, pp. 332-3.

[59] Jewkes and Gray, *Wages*, p. 205. The average is weighted by the relative size of the towns.

[60] Copeland, *Cotton industry*, p. 300.

[61] 1905 US Census, p. 60. For consistency we would prefer to use the 1909 Census, but this does not contain equivalent data.

[62] Copeland, *Cotton industry*, p. 298.

[63] 1906 Enquiry p. 30 and Jewkes and Gray, *Wages*, p. 121. Copeland's 1912 ring wages example also has wages per spindle falling as count increased, Copeland, *Cotton industry*, p. 299

[64] 1886 Wage Enquiry, p. 2.

[65] Jewkes and Gray, *Wages*, p. 122.

[66] For clarity figure two shows only New England ring output per head on the constant spindles per head basis. On the varying spindles per head basis, productivity at count 16 was 16% lower, equal at count 30, and 9% higher for all counts over 42.

[67] Clark, 'Why?', p. 152.

[68] Toms, 'Windows', p. 5.

[69] US Tariff Board, *Report*, pp. 417-420.

[70] US 1905 Census, p. 14, 1906 Enquiry, p. xviii.

[71] US Tariff Board, *Report*, p. 11.

[72] Wage lists: HBL Lyman collection, LO-1, Earnings, HBL Lyman collection, MAE-9.

[73] 1907 UK Census, p. 293.

[74] Saxonhouse and Wright, 'New evidence', p. 511

[75] 1909 US Census, p. 56.

[76] Magee, *Paper*, p. 77, Broadberry, *Productivity race*, p. 204.

[77] Broadberry, *Productivity race*, p. 10, Sandberg *Decline*, pp. 134-135.

[78] Marshall, *Principles*, p. 225.

[79] Marshall, *Industry and trade*, p. 601.

[80] Parker, 'Report', pp. 25-26.

[81] Copeland, *Cotton industry*, p. 294.

[82] Rose, *Firms, networks and business values*, ch 2.

[83] Farnie, *English cotton industry*, pp. 73, 303, 307.

[84] Nickell, 'Competition', p. 741. Other papers reaching similar conclusions for the modern economy include: Geroski, 'Innovation', Haskel, 'Imperfect competition', Hay and Liu, 'Efficiency of firms, Nickell, Nicolitsas and Dryden, 'What makes firms', Nickell, Wadhwani and Wall, 'Productivity growth', Dutz and Hayri, 'Competition', while Broadberry and Crafts, 'British economic policy' reaches the same conclusion for 1950s Britain.

[85] Szymanski, 'Tendering'.

[86] US Tariff Board, *Report*, pp. 417-420.

[87] Broadberry, *Productivity race*, p. 66.

[88] UK Statement of Trade, 1905, table 2.

[89] McCraw and Tedlow, 'Ford', p. 283.

[90] Saul, 'Motor industry', p. 25.

[91] Bardou et al, *Automobile revolution*, p. 74.

[92] McCraw and Tedlow, 'Ford', p. 283.

[93] Broadberry, *Productivity race*, pp. 53-56.

[94] Amoskeag Collection DN-2, Lyman Collection MED-5 and AD-9, Naumkeag Collection HA-5